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**A COMPREHENSIVE EVALUATION OF THE
LOWER MUSSELHELL RIVER STUDY MONITORING PLAN
AND EVALUATION OF THE WATER QUALITY OF THE
LOWER MUSSELHELL RIVER**

by

O'Brien Hollow

B.S. Oregon State University, Oregon 1997

presented in partial fulfillment

of the requirements

for the degree of

Master of Science

The University of Montana—Missoula

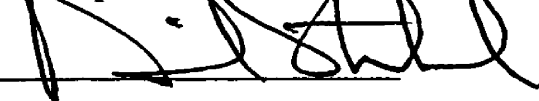
Missoula, Montana

May 2005

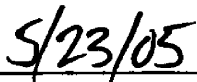
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A Comprehensive Evaluation of the *Lower Musselshell River Study* Monitoring Plan and Evaluation of the Water Quality of the Lower Musselshell River

Chairperson: Donald F. Potts



This thesis is a component of the Lower Musselshell River study. The Musselshell River is a dynamic river system. The hydrology, soils, vegetative characteristics, and land management in the area compound the difficult task of analyzing water quality data and evaluating the factors which affect water quality.

This thesis involved collection of new water quality data: flow, water temperature, conductance, total dissolved solids, total suspended solids, nitrates/nitrites, total phosphorous, and fecal coliform and periphyton composition data. Also, completed was the statistical evaluation of historic water quality data collected by the U. S. Geological Survey (USGS) and the Montana Department of Environmental Quality at the Mosby Bridge USGS gauging station at Mosby, Montana; 1972 to 1995.

The main goals of this thesis were: to assess/evaluate the validity and practicality of the study plan and to describe the seasonal variation for total dissolved solids, total suspended solids, total phosphorous, total nitrogen, nitrates/nitrites, and fecal coliform concentrations for the Lower Musselshell River.

Results from six sample periods conducted during the Lower Musselshell River study exhibit significant changes in each water quality parameter measured from site to site. The effects of recent rainfall events were observed on August 19, 1999 and July 20, 2000 the latter being a 100 year precipitation event within the study area. Pooled water and baseflow periods were also observed. With only six sample periods representing each of the nine sample sites within the study area, it is not plausible, in this study, to identify statistically significant spatial and temporal trends in water quality within the study area nor is it practical to fund continuous sampling at the intensity of this study.

With the use of historic water quality data definitive seasonal patterns were observed for total dissolved solids, total suspended solids, total phosphorous, total nitrogen, nitrates/nitrites, and fecal coliform concentrations for the Lower Musselshell River. This finding supported the hypothesis of future use of the USGS Station at Mosby, MT for describing water quality of the Lower Musselshell River.

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The author appreciates the generous funding support received from the Montana Department of Environmental Quality EPA/Montana DEQ 319 grant and the Montana Department of Natural Resource Conservation Renewable Resource grant monies. Special thanks to the Petroleum County Conservation District for sponsorship of the Renewable Resource grant and the Garfield County Conservation District for their cooperation. Thank you to the USDA Natural Resource Conservation Service in Jordan and Winnett, Montana for technical support and for their continued help and knowledge of the region. Thank you to Amy Chadwick and Donna Defrancesco for direction and continual guidance.

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Environmental Protection Agency (EPA) Region 8
Montana Department of Environmental Quality (Montana DEQ)
Montana Department of Natural Resources and Conservation (Montana DNRC)
Garfield County Conservation District

Riparian and Wetland Research Program Office Manager: Cate Crue and Vicki Rostovich

Riparian and Wetland Research Program staff and graduate students: Donna Defrancesco, Amy Chadwick, Bill Thompson, Daniel Covington, Jack McWilliams, and J. Gant Massy.

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INTRODUCTION

The Riparian and Wetland Research Program, School of Forestry, University of Montana was contracted in May 1999 by the Montana Department of Environmental Quality and the Montana Department of Natural Resource Conservation to design and implement a monitoring plan to gather baseline data to facilitate a long term study of the Lower Musselshell River watershed.

Long term monitoring sites were established by this author and other Riparian and Wetland Research Program personnel along the 115 km (74.2 miles) of river comprising the Lower Musselshell River from 13 km (8 miles) south of Mosby, Montana to the Charlie M. Russell Wildlife Refuge at Fort Peck Reservoir. Nine water quality sites were established and samples were taken three times per year for two years. Six reaches, spanning 100 to 300 meters, within the study area were evaluated using riparian inventories, channel cross section surveys, and other geophysical measures including Wolman pebble counts. Of the 115 km (74.2 miles) of river, 32 km (20 miles) were inventoried for stream classification, habitat and community type, and health and function of the riparian corridor and river channel. This study will provide recent information that can be used to update information on watershed planning and water quality condition in Montana Department of Environmental Quality (Montana DEQ) 305(b) reports. Results from this project will be used as baseline monitoring for a Total Maximum Daily Load (TMDL) plan currently being developed for the Lower Musselshell River priority area. Information about the effectiveness of the monitoring methods used will be incorporated into the TMDL plan to ensure that future monitoring will be as efficient and effective as possible.

Workshops, school field trips and a project tour were performed and facilitated by the Riparian and Wetland Research Program and the USDA Natural Resource Conservation Service of Winnett and Jordan, Montana. Project information and educational information were disseminated through watershed meetings, conservation district meetings, and through a web page constructed for the study.

This thesis is a component of the Lower Musselshell River study. The author acted as a research assistant for the Riparian and Wetland Research Program, School of Forestry, University of Montana in performing many of the tasks required by the study contracts. The goals of my thesis are to evaluate the validity and practicality of the water quality monitoring plan designed for the Lower Musselshell River Study, by the Riparian and Wetland Research Program (RWRP) and to use the data acquired from the RWRP monitoring and historical data acquired from the Montana Department of Environmental Quality and the U.S. Geological Survey to describe the seasonal water quality of the Lower Musselshell River.

Project History

A local group of farmers and ranchers along the Lower Musselshell River formed the Mosby/ Musselshell River Group in the winter of 1998 to address their common resource and water quality concerns. The focus of the group was to implement site specific and watershed-wide improvements that would address their common concerns. The goal of these improvements was to improve the water quality, water distribution, and riparian and rangeland health of the Lower Musselshell River, which in turn would benefit local ranch operations and the ecology of the Lower Musselshell River Watershed.

With the passage of the 1972 federal Clean Water Act, states were directed to develop Total Maximum Daily Loads (TMDLs) that set limits on point and non-point source pollution loading to waterbodies, including streams and rivers that do not meet or are not expected to meet state water quality standards, including flow alteration and riparian habitat alteration. Voluntary cooperation by all affected parties in a watershed is the preferred method of TMDL development and implementation in Montana (MT DEQ 2000). Voluntary TMDLs are currently being developed within the Lower Musselshell River watershed by landowners and the Montana DEQ.

Three tributaries located within the Lower Musselshell River watershed (Calf Creek, Blood Creek and Lodgepole Creek) have also been listed by the Montana DEQ as LOW

priority waterbodies for Total Maximum Daily Load (TMDL) development. The Montana Department of Natural Resources and Conservation (DNRC) has determined that the Musselshell River meets the criteria for designation as a chronically dewatered watercourse as codified in Montana Code Annotated (MCA) 85-1-250.

The Lower Musselshell River (Montana Waterbody Number MT 40A001-1) was listed by the Montana Department of Environmental Quality (Montana DEQ) 303(d) list as a MODERATE priority waterbody in need of Total Maximum Daily Loads (TMDLs) development for the 1998-2000 biennium. The Lower Musselshell River is now listed as a HIGH priority waterbody under the 2000-2002 biennium 303(d) list (MT DEQ 2000). The river is listed on the 303(d) list as impaired for chronic dewatering and riparian habitat alteration and in need of Total Maximum Daily Load (TMDL) development (Table 1). The Montana DEQ 303(d) list is a prioritized list (HIGH, MODERATE, and LOW priority) of rivers, streams, and other bodies of water within the state that do not meet state water quality standards and are in need of TMDL development.

Table 1. Department of Environmental Quality 2000-2002 303(d) list.

Hydrologic Unit Code		10040205	Watershed		LOWER MUSSELSHELL	
ID Segment	ID Waterbody Segment		Size	Use Class	Probable Causes of Impairment	Probable Sources of Impairment
1 MT40C0 03_010	MUSSELSHELL RIVER, from Flatwillow Creek to Fort Peck Reservoir		74mi	C-3	Flow Alteration Other Habitat Alterations Riparian Degradation Bank Erosion Modification of Banks	Agriculture Grazing Sources Erosion & Sediment Flow Regulation Modified/ Destabilized
Use Support						
Aqua Life	Cold Fish	Warm Fish	Drink Water	Swim (Rec)	Agri	Ind.
Partial	n/a	Partial	n/a	Full	na	na

Twelve Environmental Quality Incentives Program (EQIP) contracts have been initiated among members of the Mosby/Musselshell River group and other local landowners in order to meet the goals of the Mosby/ Musselshell River Group and the goals of the Clean Water Act and TMDL program. The EQIP program is a federal cost share program administered by the USDA Natural Resource Conservation Service designed to make

land management improvements that will improve the health of an ecosystem. The EQIP contracts along the Lower Musselshell River call for improvements in water use efficiencies for irrigation and improving rangeland health through riparian fencing, off site water, and rotational grazing systems. The Riparian and Wetland Research Program, School of Forestry, University of Montana monitored these changes through water quality and quantity sampling and riparian area inventories along 115 km (74.2 miles) of river. This EQIP project is a demonstration project for investigating influences of agricultural practices on water quality, stream condition, and rangeland health.

Description of Water Quality Problems

The lower portion of the Musselshell River is a fourth order, perennial flowing waterbody. Flow peaks in spring after snowmelt and diminishes by late summer. The river's waters are classified as suitable for bathing, swimming, recreation, and growth and propagation of non-salmonid fishes and associated aquatic life, waterfowl, and furbearers (Table 1).

Unfortunately, approximately 75 km (47 miles) of the Lower Musselshell River are only partially supporting its beneficial uses. Lodgepole Creek and Calf Creek, tributaries to the Lower Musselshell River are only partially supporting their beneficial uses. These impaired beneficial uses include aquatic life support and warm water fishery as identified in the Montana DEQ 303(d) list.

Causes

The probable causes of impairments, as identified in the 2000-2002 biennium 303(d) list, include flow alteration, other habitat alterations, riparian degradation, bank erosion, and modification of stream banks (Table 1). Other resource concerns within the watershed include water quantity issues relating to low irrigation efficiencies and insufficient instream flows on a chronically de-watered river, degraded range from historically poor livestock distribution and grazing practices, loss or degradation of riparian habitat, irrigation induced erosion, and invasion of noxious weeds. There are no known point sources of pollution within the watershed.

Existing Data

Though the Lower Musselshell River and its tributaries are listed for impairment of aquatic life support and warm water fishery, there is insufficient data on ambient water quality at present to determine aquatic habitat health. The EPA 1997 Index of Watershed Indicators report reflects this lack of data availability, indicating insufficient data in the categories of ambient water quality-toxics, ambient water quality-conventional and aquatic species at risk.

According to a recent study of water quality conducted on the upper and middle portions of the Musselshell River (from North and South Forks to Mosby), water quality on the Lower Musselshell River exceeds State Water Quality Standards for total dissolved solids, including sodium and alkalinity (Musselshell River Basin Water Management Study 1998). This thesis will augment the information collected for the Upper and Middle Musselshell River by providing water quality data on the segment from Mosby downstream to Fort Peck Reservoir.

Project Area and Watershed Description

The Lower Musselshell River is defined by the Montana Department of Environmental Quality 303(d) list as the last 115 km (74.2 miles) of the entire river. The Lower Musselshell River divides Garfield county to the east from Petroleum county to the west.

This thesis project was implemented within the Lower Missouri TMDL Development Focus Area in eastern Montana, which is located in the Lower Musselshell River hydrologic unit (HUC 10040205). This includes 72,997 hectares (182,494 acres) of the Lower Musselshell watershed in Garfield, Petroleum, and Rosebud Counties. The project area stretches from 13 km (8 miles) south of Mosby, Montana, 53 km (33 miles) north to the confluence of the Missouri River at Fort Peck Reservoir (Fig. 1). It includes the legal area from Township 13 North, Range 29 East to Township 18 North, Range 29 East and comprises parts of U. S. Geological Survey hydrologic units 10040205 and 10040202.

The Musselshell River Watershed drains approximately 22,144 km² (8,550 square miles) of central Montana. Flows originate in mountain catchments as far south as the Crazy Mountains and west to the Big Belts. These catchments converge near the town of Martinsdale to form the Musselshell River. From its headwaters, the river flows for approximately 422 km (264 miles) to Melstone, Montana. From Melstone the river flows north for about 208 km (130 miles) before it enters Fort Peck Reservoir on the Missouri River. The Musselshell River flows through open range, irrigated and non-irrigated farmland and cottonwood bottoms until its confluence with the Missouri River (Fig. 1).

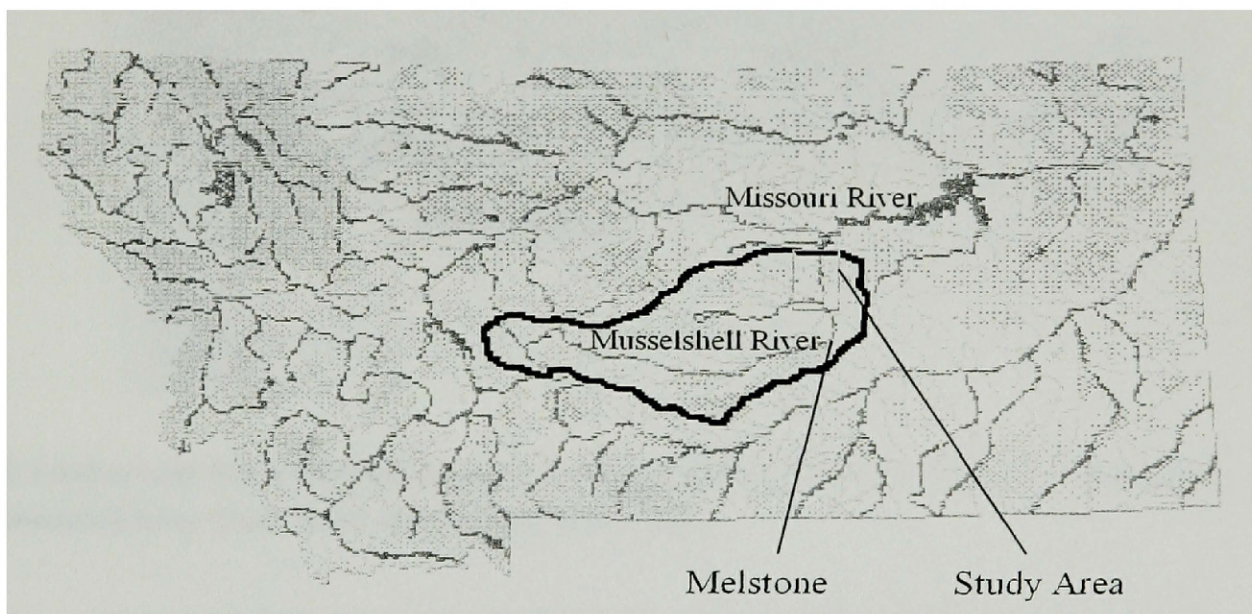


Figure 1. Map of Montana with the Musselshell River Watershed delineated and study area location.

Land ownership is distributed as 30,800 hectares (77,000 acres) of federally owned land and 43,200 hectares (108,000 acres) of nonfederal land (Fig. 2). The project area also includes two designated USDI Bureau of Land Management Wilderness Study Areas and the north end adjoins the USDI Charles M. Russell Wildlife Refuge (Musselshell River Basin Water Management Study 1998).

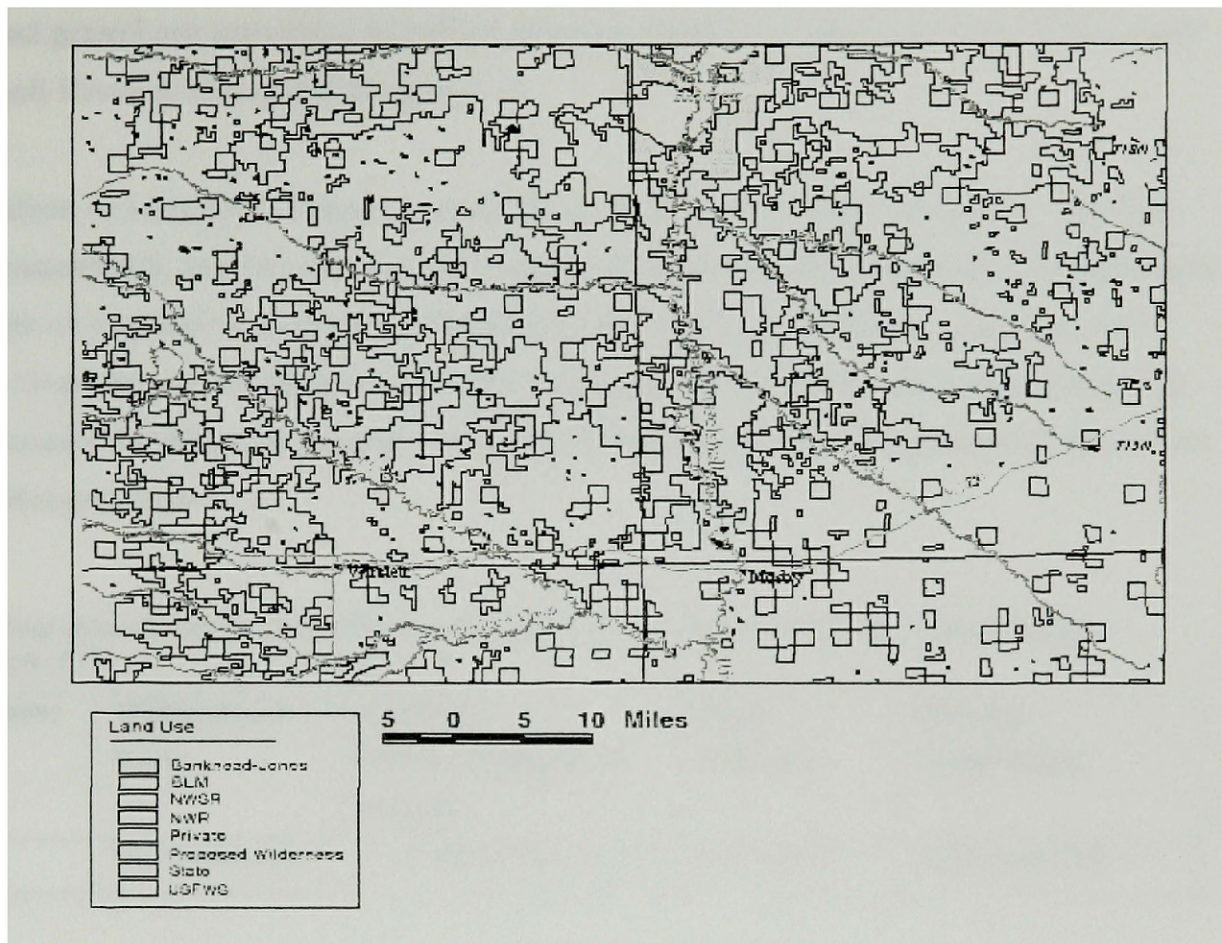


Figure 2. Land use and land ownership along the Lower Musselshell River Study area and surrounding area (Musselshell River Basin Water Management Study 1998).

A majority of the alluvial plain is privately owned. Land use along the Lower Musselshell River is dominated by irrigated agriculture. The land is fertile and averages 163 growing degree days. Hay crops are typically alfalfa and barley. Corn silage is also produced along the river. During calving and drought years livestock can be found along the river. Livestock and irrigated and farming are the major water uses along the Lower Musselshell River (Musselshell River Basin Water Management Study 1998).

Contributing tributaries to the Lower Musselshell River are predominantly ephemeral and intermittent. Flat Willow Creek near the southern boundary of the project area is perennial. The alluvial plain averages 1.6 km (1 mile) wide, ranging from 0.8 km (0.5 mile) to over 3.2 km (2 miles) wide. The entire length of the river within the study area is

considered moderately entrenched with bed material dominated by sands and silts. Cobble and gravel are prevalent in riffles along the length of the study area. The Lower Musselshell River is classified Rosgen C/4.

Classification of streams is based on multiple stream or river characteristics. The five main characteristics used by the Rosgen Stream Classification System are: entrenchment ratio; depth of channel compared to the floodplain, width/depth ratio, sinuosity; how much the river meanders, slope of the river channel, and channel bed composition. The Lower Musselshell River is classified Rosgen C/4 based on the characteristics shown in Table 2 (Rosgen 1996).

Table 2. River characteristics for the Lower Musselshell River used to determine Rosgen Stream Classification; C/4

Entrenchment Ratio	Width/Depth Ratio	Sinuosity (River length/linear length)	Slope (rise/run)	Channel Composition
> 2.2	>12 (Moderate)	> 1.2 (High Sinuosity)	0.001-0.02	Gravel and Silt

Geologic History

The Lower Musselshell River is actively cutting through many layers of geologic history. The most prominent geologic formation within the study area is the Cat Creek Anticline which forms an east west ridge and many of the buttes in the surrounding upland area. The Cat Creek Anticline runs through the upper reaches of the study area crossing the river near Mosby, Montana. North of the ridge is the Bear Paw Shale and Hell Creek Formations. South of the ridge is dominated by older cretaceous rocks. The Bear Paw Shale Formation and Hell Creek Sandstone Formation are the dominant rock types found in the study area. They are highly erodible and help to form the topography of the surrounding area. Both of these formations represent the deposits at the margins of an ancient cretaceous sea, which inundated the region for millions of years as the sea made its final retreat eastward. Sandstone and shale of the Hell Creek Formation, which are the youngest consolidated rocks in the area, overlie the shale of the Bear Paw formation. The

present riverbed of the Lower Musselshell River has cut down to the upper portion of the Bear Paw Shale Formation (Lindahl 1993 and Hyndman and Alt 1991).

According to the area soil survey (Lindahl 1993), the Musselshell River is situated in a myriad of marine, lacustrine, and alluvial sediments, which are primarily fine grained sand, silts, and clays. Clay and loam dominate the uplands and sandy loam dominate the floodplain. Two dominant soil types are found in the alluvial plain of the study area. The Havre soils are found in the first 83 km (52 miles) of river within the study area. Soils then make the transition to Crago soils, which are found in the last 33 km (20 miles) of river within the study area, as defined by the Natural Resource Conservation Service Soil Survey of 1993 (Lindahl 1993). The Havre soils are described as deep well drained, moderately to fine textured soils. They are considered to be free of salt and sodium. These soils are considered highly erodible. The Crago soils are deep well drained moderate-coarse to medium textured soils. Gravels are typically found at depths of 80-240 cm (20-60 inches) in the Crago soil types. These soils are considered highly erodible.

Description of Riparian Area and Associated Vegetation

Riparian areas, the interface between aquatic and terrestrial ecosystems, provide many essential services, including stabilizing and building stream banks, dissipating stream energy, filtering sediment and other pollutants, storing water and recharging the aquifer, and providing habitat for fish and wildlife. Riparian areas provide attractive areas for outdoor enthusiasts, and uplands associated with riparian areas support more livestock per acre than any other range area (Skovlin 1984). Pictures of water quality sample sites 1, 4, 5, and 9 are shown in Figure 3. These pictures depict the tremendous diversity of characteristics of the riparian corridor within the study area.

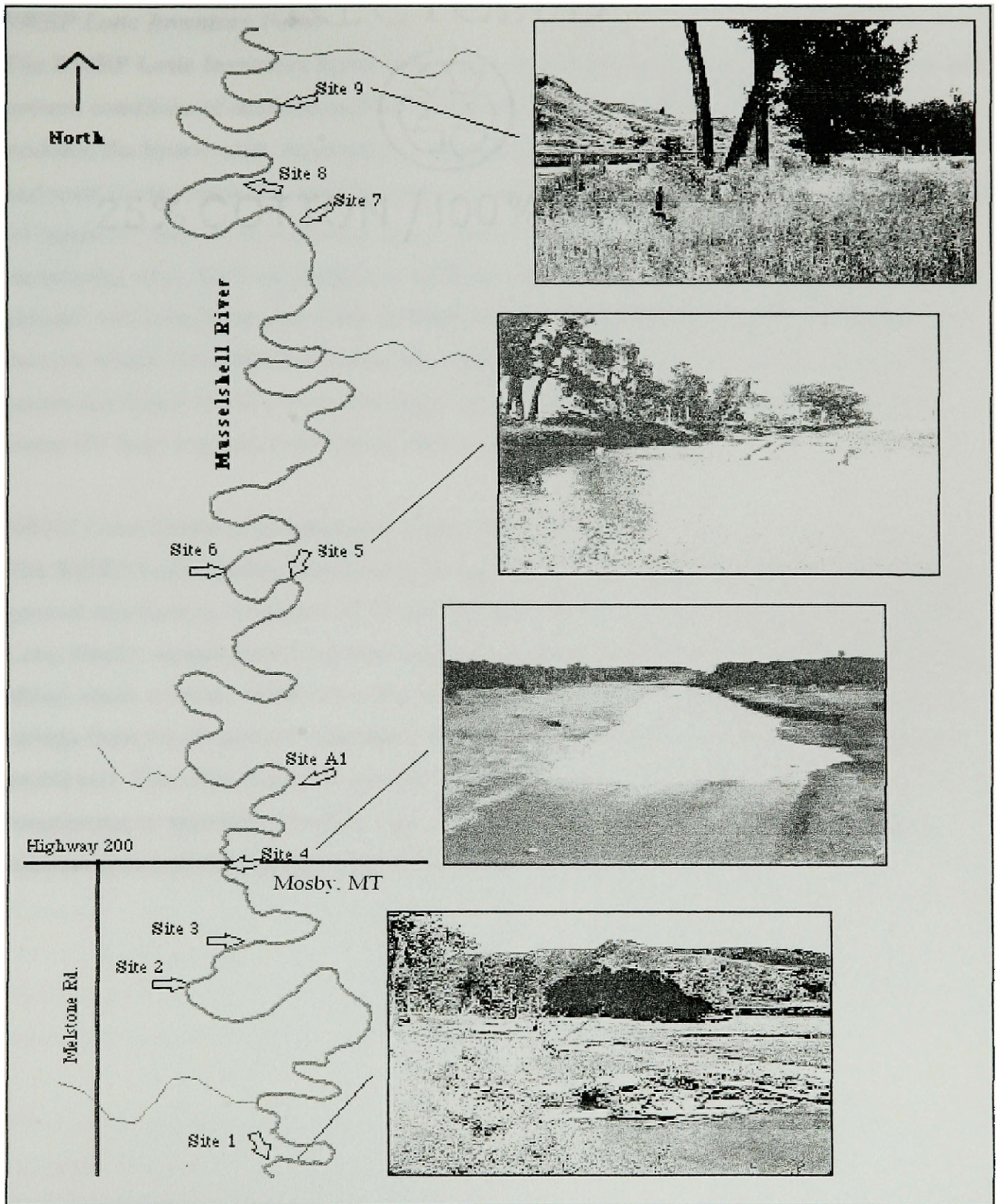


Figure 3. Study area map with accompanying pictures of Sites 1, 4, 5, and 9 during similar flow and season.

RWRP Lotic Inventory Form

The RWRP Lotic Inventory Form was used to evaluate and characterize the function and present condition of selected reaches within the riparian corridor. The form was used to evaluate the hydric soils, hydrophytic vegetation, and wetland hydrology of sample sites and used to determine the overall health of the sample sites. The inventoried reaches were 50 meter (97 feet) wide transects within study reaches coinciding with water quality monitoring sites. Derived health scores from the RWRP Lotic Inventory ranged from 77 percent which indicates the reach is functional at risk (healthy but with problems) to 44 percent which indicates the inventoried reach is not functioning properly. Site specific scores are found at www.rwrp.umt.edu. Site scores are only representative of the 50 meter (97 feet) transect from which they were derived.

RWRP Lotic Health Assessment for Large River Systems

The RWRP Lotic Health Assessment for Large River Systems was used to evaluate the general functioning condition of 32 km (20 miles) of the river study area. Each RWRP Lotic Health Assessment Form for Large Rivers represented approximately 0.8 km (0.5 miles) reach of river. Ninety-two percent of the reaches inventoried showed a range of ratings from 60-80 percent indicating the stream is functioning at risk (healthy but with problems). The other 8 percent scored less than 60 percent, indicating they are not functioning to maintain a healthy riparian community. Table 3 shows the dominant habitat types and community types identified.

Table 3. Percent cover of Habitat Types and Community Types identified on 32 km of river within the Lower Musselshell River study area; adapted from the RWRP Lotic Inventory Form

Habitat Type or Community Type	Total River Inventoried 32 km (20 mi.)
	Percent of Total
Great Plains cottonwood/recent alluvial bar CT	38%
UNCLASSIFIED	21%
American licorice CT	7%
Silver sagebrush/western wheatgrass HT	6%
Great Plains cottonwood/western snowberry CT	6%
Sandbar willow CT	3%
Sharp bulrush HT	1%
Common spikesedge HT	1%

The dominant vegetation habitat and community types based on the Riparian and Wetland Research Program Health Assessment for Large Rivers are descriptive of a narrow band of vegetation paralleling the river ranging from 3-100 meters (10-328 feet) from the waters edge. Some of the community and habitat types are well established, where as the habitat type Great Plains cottonwood/ recent alluvial bar is dependent on many hydrologic factors for it to become well established (Rood and Mahoney 1995). Thirty eight percent of the study area's riparian vegetation was classified as the habitat type Great Plains cottonwood/ recent alluvial bar (*Populus deltoides*/ recent alluvial bar). Seven percent of the land paralleling the river was classified as upland, primarily shrub land dominated by mid height grasses and Silver Sage brush (*Artemisia tridentata*). American Licorice community type (*Glyceria lepidosa*), Great plains cottonwood/ Snowberry community type (*Populus deltoides*/ *Symphoricarpos albus*), Sand Bar Willow community type (*Salix exigua*), and Bull rush habitat type (*Eleocharis palustris*) were the other predominant vegetation types found along the river.

Health scores broken out by selected categories are shown in Table 4. These categories represent the pertinent criteria which are used to determine the health scores derived from the RWRP Lotic Health Assessment for Large River Systems. Table 4 highlights several of the categories which combine to yield a low health score. Cover of woody species, bank root mass, presence of invasive plants, lack of native graminoids, and dewatering

contribute to the low health scores received. Several positive highlights are the lack of human-caused bare ground, few exotic woody species, high shrub regeneration, and high cottonwood regeneration, as well as, high densities of dead/decadent woody species including cottonwoods.

Table 4. Health scores as a percent of 100, representing categories used in the RWRP Lotic Health Assessment for Large River Systems health evaluation score.

Categories Used in the RWRP Lotic Health Assessment for Large Rivers to Determine River Health Score	Actual Score	Possible Score	Health Score per Category as a Percent of 100
Exotic woody species	2.9	3	96%
Alteration to banks	8.7	9	96%
Shrub regeneration	2.8	3	94%
Dead/decadent woody species	2.8	3	93%
Human-caused bare ground	5.5	6	91%
Cottonwood regeneration	5.0	6	83%
Undesirable herbaceous species	2.2	3	74%
Control of peak flows	6.0	9	67%
Floodplain accessibility	4.0	6	66%
Utilization of trees/shrubs	1.9	3	63%
Invasive plant species	3.6	6	59%
Cover of woody species	1.4	3	46%
Bank root mass	2.5	6	41%
Dewatering	3.0	9	33%
Native grasses	0.3	3	10%

An important and useful component of the lotic inventory was the evaluation of the distribution and percent infestation of invasive and weedy species along the riparian corridor. Table 5 shows the percent infestation of weedy and invasive species along the Lower Musselshell River. Salt cedar is the most prolific invasive species along the river. Canadian thistle and knapweed species are also common along the river corridor. A future evaluation of the weed infestation, especially salt cedar, along the Lower Musselshell River will be important in evaluating the health of the river system.

Table 5. Percent cover of invasive plant species identified on 32 km (20 miles) of river within the Lower Musselshell River study area.

Invasive Plant Species (by Common Name)	Total River Inventoried 32 km (20 mi.)
	Percent of Total Area Infested
Salt Cedar	13%
Canada Thistle	2%
Russian Olive	1%
Russian Knapweed	0.5%
Spotted Knapweed	0.5%
Leafy Spurge	0.5%

Separate measures of woody browse and human and animal caused bank alteration are shown in Table 6. These measurements were taken at the six transect sites along the river. The table shows that this means of determining animal and human use and/or disturbance along the transects can show site specific problems. This information can not be used to characterize reaches that were not evaluated.

Table 6. Indicators of river corridor use for selected sites. Shrub browse and human and animal caused bank alteration shown as a percent of the total available.

Site number	Percent Shrub Browse	Percent Human Caused Bank Alteration	Percent Animal Caused Bank Alteration
Site 1	25-50%	5-25%	25-50%
Site 2	<5%	5-25%	<5%
Site 3	<5%	<5%	<5%
Site A1	<5%	<5%	<5%
Site 5	<5%	<5%	<5%
Site 9	<5%	5-25%	<5%

Human-caused bank alteration includes pump site installations and river fords. Animal caused bank alteration is signified by hoof sheer, pugging, and watering trails. Percent browse was only determined for woody species. Browse of grass species was less than 5 percent for all of the sites observed except Site 1, which had approximately 25-50 percent shrub browse. Site 1 is a water gap used during winter and drought years. Through management changes the water gap will no longer be used. Stock water tanks are being placed several miles from the river in the same pasture as the water gap. This Best Management Practice (BMP) implementation has the potential to improve the riparian

cover of this area, improve bank stability, and reduce upland erosion by reducing intense livestock use of the area (Skovlin 1984).

FOCUS AND OBJECTIVES

This thesis is a component of a project executed by the Riparian and Wetland Research Program, School of Forestry, University of Montana, titled: *Lower Musselshell River Study* (Hollow and others 2001). The Lower Musselshell River Study was initiated by the Mosby/Musselshell River Group, which was formed in 1998 to address common local resource concerns of water quality, quantity, and rangeland health. The local and regional water quality concerns of landowners, operators, and local agency persons inspired this thesis.

The goals of this thesis are to evaluate the validity and practicality of the water quality monitoring plan designed for the Lower Musselshell River Study, by the Riparian and Wetland Research Program (RWRP) and to use RWRP's monitoring data and historical data from the Montana Department of Environmental Quality and the U. S. Geological Survey to describe the seasonal water quality of the Lower Musselshell River.

Objectives

- A) To assess/evaluate the validity and practicality of the Lower Musselshell River monitoring plan within the context of the following questions:
 - a) Is the monitoring plan statistically rigorous? Is it capable of identifying statistically significant spatial and temporal trends?
 - b) Is the monitoring plan economically feasible?
 - c) Is the monitoring plan repeatable by other people doing follow-up monitoring?
- B) Describe the seasonal variation in concentrations of total dissolved solids, total suspended solids, total phosphorous, total nitrogen, nitrates/nitrites, and fecal coliform for the Lower Musselshell River.
 - a) Are there patterns in the variation?
 - b) What are the monthly maximums, minimums, and averages?
 - c) Can the Mosby USGS Gauging station be used to describe the seasonal variation of water quality measures.

STUDY DESIGN

This thesis involved collection of new water quality and periphyton composition data, and the statistical evaluation of historic water quality data collected by the U. S. Geological Survey (USGS) and the Montana Department of Environmental Quality at the Mosby Bridge USGS gauging station at Mosby, Montana. Figure 4 is a site map for the study area.

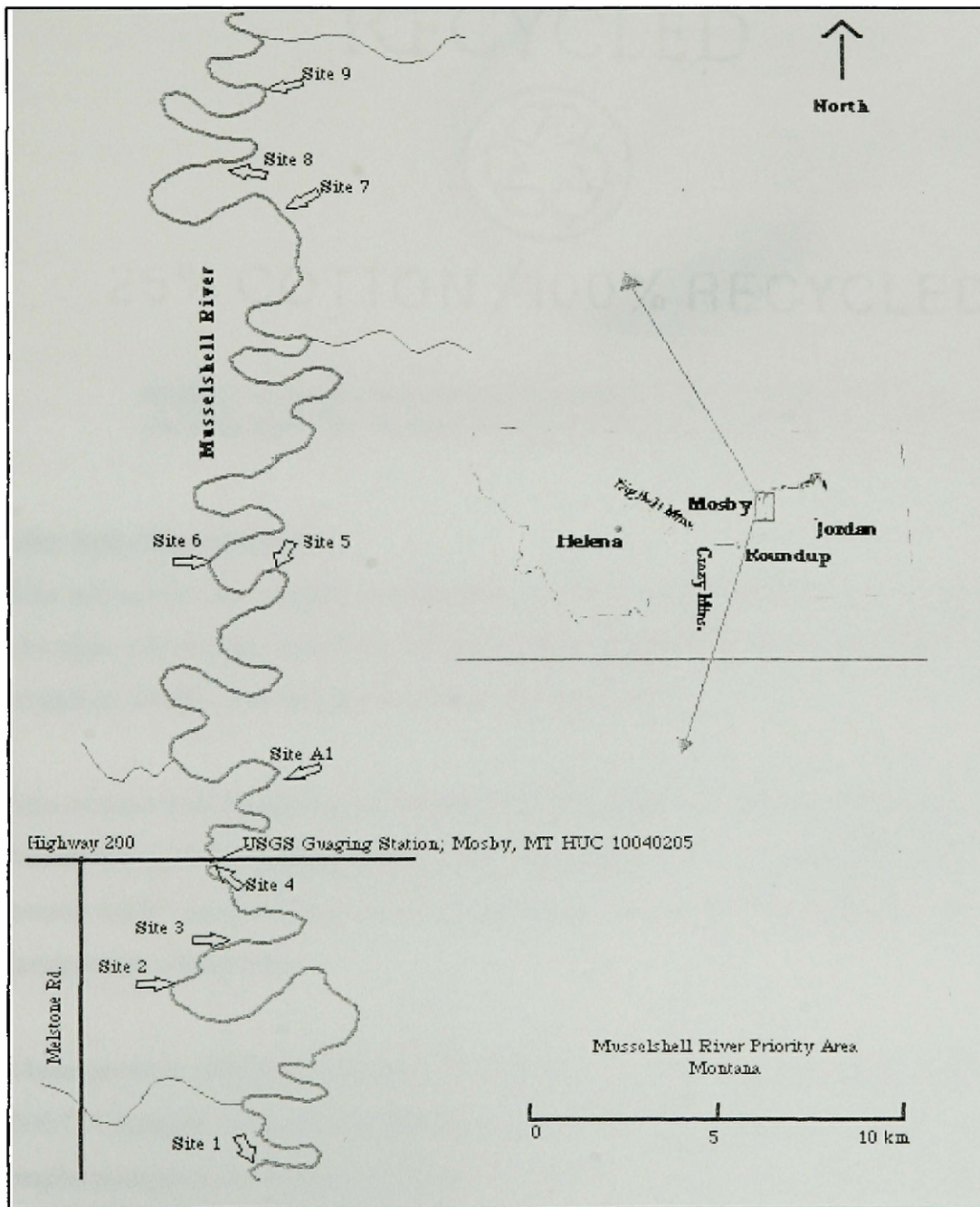


Figure 4. Site map for the Lower Musselshell River Study

Water quality and quantity monitoring sites coincided with periphyton sampling sites and with riparian inventory sites referred to in the Introduction of this thesis. Figure 4 is an example study reach, typical of many studied reaches along the Lower Musselshell River.

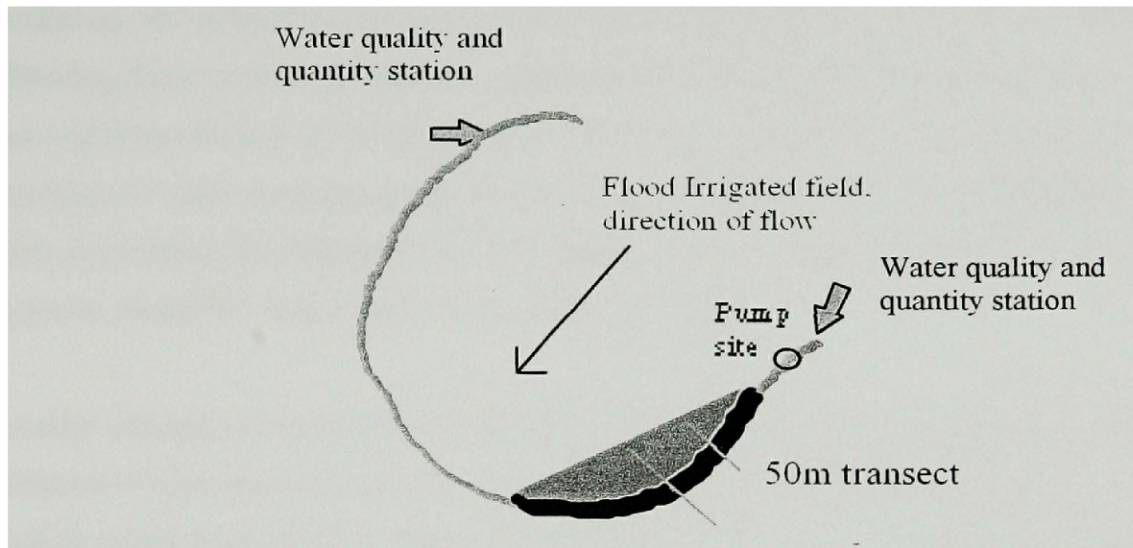


Figure 5. Example reach including upstream/ downstream water quality monitoring and a Riparian and Wetland Research Program Lotic Inventory 50m transect.

Site Selection Criteria

Site selection was based on multiple criteria including site access, type of management changes occurring, location of drain fields and pump sites, direction of drainage of irrigated fields, and location within the study area.

Site access was based on availability of passable roads to or near the study site.

Minimizing the crossing of hay fields and irrigation structures was also considered. The entire study was performed on private land, therefore travel restrictions were based on landowner discretion.

Management changes included in the site selection criteria were implemented from 1998-2001. Changes included installation of off-site watering, riparian fencing, gated pipe and implementation of livestock rotation systems. Each of the four management changes were identified based on location within the study area. Water quality sites were located so as

to capture surface or subsurface flows to the river from areas where management changes were being implemented.

Location and direction of drainage from flood irrigated fields and location of pump sites were included as site selection criteria in order to minimize the number of confounding factors affecting flow and water quality. Water quality sites were placed upstream of pump sites and downstream of drainage areas in order to capture the water quality effect of the irrigation or other management changes. The reaches were not extended beyond this because increasing the distance of river being monitored increases the likelihood of capturing more variables affecting water quality and flow.

Sites were also chosen based on their location within the respective study area. Both the top and bottom of the entire study area were monitored in order to get a better understanding of the total effect of management changes and natural variation of water quality and flow. Sampling reaches were interspersed throughout the Lower Musselshell River to attain a representative sample of the entire study area.

Surface Water Quality and Quantity Monitoring

The monitoring strategy for the Lower Musselshell River Watershed Plan included water quality and quantity monitoring of flow, water temperature, conductance, total dissolved solids, total suspended solids, nitrates/nitrites, total phosphorous, and fecal coliform. Sites were established at the upstream and downstream ends of each study reach on the river. Sample sites were placed directly downstream of any ephemeral or intermittent streams. Many tributaries are not shown in Figure 5.

The water quality monitoring is an upstream/downstream design for nine reaches and includes the top and bottom of the study area (Fig. 5). Site selection criteria were based on multiple variables including site access, type of management changes occurring, location of drain fields and pump sites, direction of drainage of irrigated fields, and location within the study area.

The nine sample sites were distributed throughout the 115 km (74.2 miles) of river within the study area. Figure 5 shows the respective location of water quality sampling sites along the study area. Samples were taken on the same day from each of the study sites. Sampling periods were selected based on a flow driven monitoring scheme. The Mosby U. S. Geological Survey gauging station was used to monitor the flow of the river and to determine the rising and falling limbs of the hydrograph and periods of base flow. The first sample of the field season was taken during the rising limb of the hydrograph. A second sample was taken during the falling limb of the hydrograph, which also corresponds to heavy irrigation periods. These two sample periods are important in capturing the effects of high flow events associated with Spring snowmelt and rainfall events. A third sample was taken during baseflow after irrigation within the study area had ceased. Baseflow is defined as river flow being dominated and sustained by groundwater inputs from the surrounding watershed. Two storm runoff events were also captured during the field seasons. The dates sampled were August 19 and September 28, 1999; June 5, July 20, August 19 and 27, and November 8, 2000

Water quality sites were monumented with capped rebar in order to locate the same site for each sampling period. A tag line was drawn across the channel perpendicular to the thalweg. Flow was measured using the U. S. Geological Survey protocol for large rivers (Buchanan and Somers 1969). Velocity measures were taken using a Price AA velocity meter. Velocities and water quality samples were measured at an increment corresponding to 10 percent of the total width of the wetted perimeter or 25 measures, whichever was greatest. Increments were identified using a tape measure drawn perpendicular to the thalweg. A depth integrated sampler was used in order to attain a more representative collection of water quality at each transect throughout the entire depth of the water column.

Sampling and handling procedures—Sampling bottles for total dissolved solids, total suspended solids, nitrates/nitrites, total phosphorous, and fecal coliform were received from MSE-HKM labs in Butte, Montana for each sampling period. The bottles were

cleaned and disinfected by the lab in order to reduce the introduction of foreign material into the samples. Sample bottles for fecal coliform were lined with Lugol's (IKI) solution. Lugol's solution is formulated to stop fecal coliform growth and other bacterial growth in the sample during shipment. Each sample bottle was fully submerged in the water column and uniformly drawn from the top of the water column to the bottom of the river channel and up again in order to integrate the differences in concentrations of each parameter due to spatial variation in the water column.

The number of sample bottles used to collect each parameter varied with flow. Increased flow required more water to be collected in order to adequately represent the entire water column. For example, the average river flow on August 19, 1999 of 138 cubic feet per second (cfs) required two to three sample bottles per water quality parameter at each respective sample site. One sample bottle per water quality parameter at each site was used for an average river flow of 9 cfs during the sample date November 8, 2000.

Each sample bottle was labeled with the sample date, site identification of sample location, initials of the collector, and parameter to be analyzed. Immediately after each set of samples from a sample site were collected they were capped, sealed with parafilm, and placed in a cooler containing frozen water packs. Reduced temperatures inhibits biologic activity and reduces the rate of other chemical and physical processes which can affect lab analysis results and subsequent data analysis. Samples were sent via the U.S. Postal Service within twelve hours of the initiation of each sample period within the study area. Samples were shipped in an 82 liter (80 quart) cooler with frozen water packets.

The fecal coliform samples and nutrient samples had to be received by the lab within 24 hours and 72 hours respectively. This immediacy was due to the negative changes in sample quality that may occur to these samples because of biological and chemical processes during storage and shipment.

MSE-HKM labs in Butte, Montana performed the analysis on all water quality samples taken on the Musselshell for the present project. Historic water quality samples taken by the U. S. Geological Survey and Montana Department of Environmental Quality, being used for this thesis were collected and analyzed by their own respective technicians and subcontractors.

Periphyton and Diatom Sampling

Periphyton and diatom samples were collected using the *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers* published by the U.S Environmental Protection Agency in 1999. Periphyton was measured once in late Summer 1999 and analyzed by Dr. Loren Bahls at the Montana Department of Environmental Quality. Six samples of periphyton and diatoms were collected from six respective sites coinciding with water quality Sites 1, 2, 4, 5, 7, and 9. These samples were collected by the author and another Riparian and Wetland Research Program personnel. Macroscopic periphyton (attached algae) were collected in proportion to their abundance at a given site and microscopic periphyton were scraped from natural substrates roughly in proportion to the abundance of each substrate (rocks, mud, and woody material). Substrates were scraped with a clean metal spoon or knife and were preserved in Lugol's (IKI) solution and shipped to Helena, Montana for analysis by Loren Bahls. The analysis process and QA/QC protocol are found in, Bahls 1980 The complete sampling method yields a relatively representative composite sample of each site (Bahls 1980).

Data Analysis

Several different strategies for data analysis and description were employed. Data collected by the Riparian and Wetland Research Program for the period 1999-2000 were analyzed using Microsoft Excel spreadsheets and Abascus Concepts Statview statistical software. Data sorting and calculations were created in Microsoft Excel software. Microsoft Excel bar charts were originally employed to describe monthly trends, but box plots created in Abascus Concepts Statview statistical software show the range, median and outliers of the data. This representation describes the data more appropriately. Data were organized by site and by sample period.

Historic water quality data attained from the U. S. Geological Survey and the Montana DEQ were entered into a Microsoft Excel spreadsheet. Sorting and averaging data was performed within the Microsoft Excel spreadsheet. Regression analysis and box plots were created using Abascus Concepts Statview statistical software. All of the data used represents water quality samples taken at the Mosby Bridge, defined as the junction of Highway 200 and the Musselshell River at Mosby, Montana. Samples represent monthly water quality of six parameters: total suspended solids, fecal coliform, total nitrogen, nitrate/nitrite, total phosphorous, and flow. Each of the parameters was organized based on the sample date: day, month, and year. Parameters were organized by month in order to evaluate the monthly average for each parameter over the course of the sampling period, for example from the years 1974-1992. Parameters were organized by sample date to perform regression analysis of the data. Trend analysis was also performed; data was organized by order of sample date yielding parameter values versus time.

Box plots were used to analyze each parameter by month. The box plot depicts all of the data per month. Water quality data is typically non-normally distributed (Grabow and others 1998). Box plots are robust to non-normally distributed data with multiple outliers (Ott 1993). Notable features of the box plot are the identifiable seasonal trends and the peak values indicated by circles on the extremes of the box plots.

Quality Assessment and Quality Control

Water quality sampling quality assessment and quality control (QA/QC) was performed in the field during sampling and in the lab during sample analysis. Well established and widely accepted protocol were used for all sampling work. Training was conducted in the use and care of all sampling equipment. All samples, including blanks, were handled, transported, and analyzed in the same manner.

Field assessments for quality control included duplicate samples and field blanks for selected sampling periods. Field blanks consisted of ionized water pored into sample

bottles and handled, transported, and analyzed the same as all other samples for that sample period. Table 7 shows the results of the field assessments.

Table 7. Field assessment evaluation for QA/QC for water quality samples.

Field Assessment		Total Suspended Solids	Total Dissolved Solids	Nitrates/Nitrites	Total Phosphorous	Fecal Coliform
Duplicates (mg/l)	Range	-10 to 4	- 160 to 300	+0.04	+/- 0.01	n/a
	avg.	-3	122	0.02	0	n/a
Field blanks (mg/l)	Dif. From Zero	0.01 mg/l	0.01 mg/l	Below Detection Limit	Below Detection Limit	0.01 mg/l

All data collected by the Riparian and Wetland Research Program for the purposes of this study were cleaned by Riparian and Wetland Research Program personnel using the Riparian and Wetland Research Program field data quality assurance and quality control methods (Thompson 2001).

Step 1—type the field data into a computer database onto a screen facsimile of the original field form.

Step 2—perform a visual recheck by a second person to ascertain that the field notes are faithfully duplicated in the computer.

Step 3—systematically check (using computer routines) every field to ascertain that it contains only entries that are acceptable in format and value range. When a record is found to contain an unacceptable entry (e.g., misspelling, number out of range, bad format), several remedies are available. A correction may be made in the case where there is no doubt of the intended meaning, based on corroboration in other fields, such as commentary text fields. Otherwise, the field observer may be consulted for clarification (when possible), or the unacceptable entry may be replaced with “NC” (for “not collected”) in cases where a proper entry proves indeterminate.

Step 4—systematically check (using computer routines) every field for data that may be logically inconsistent with the data held in other fields of that record. For example, a record may not logically have 100 percent vegetation cover AND 100 percent bare ground simultaneously, nor a listing of spotted knapweed infestation without inclusion of that species in the Forb lifeform list of species. Remedy for such errors is sought using the same approach as for errors found in Step 3 above.

SURFACE WATER QUALITY RESULTS

Water is one of the most useful indicators of natural and human caused disturbances to the landscape. Responses may be manifested in changes in timing, quantity, and quality of flow (Tiedemann and Higgins 1989). Water responses also provide an integrated view of the effects of the multiple management activities that occur on the landscape (Tiedemann and Higgins 1989). In the case of the Musselshell River these management activities may include, but are not limited to flood irrigation, livestock grazing, and runoff from range land, county roads, and municipal waste sites.

Because the Musselshell River transports many different constituents, ranging from nutrients and sediments to salts and metals, it is important to understand the synergistic effects, on water quality, of changes to the surrounding watershed. The water quality parameters discussed in the results are concentrations of total dissolved solids, total suspended solids, total nutrients, and fecal coliform. The results depict how parameter values vary over time and within seasons based on the available data. Variations in the data may be due to local rain events, irrigation practices, reservoir management, or seasonal fluctuations in flow and other physical, chemical, and biological factors. Periphyton results are given as narrative analyses. Concentrations of total dissolved solids, total suspended solids, total nutrients, and fecal coliform have been collected along the Musselshell River since 1972, by the U. S. Geological Survey, Montana DEQ and most recently by the Riparian and Wetland Research Program.

The following results section pertaining to water quality data is organized by two primary subject headings: “Riparian and Wetland Research Program Data and Analysis” and “Historical Water Quality Data and Analysis.” These primary subject headings are then further divided by each analyzed parameter. Figures and Tables accompany each analysis.

Riparian and Wetland Research Program Data and Analysis

The Riparian and Wetland Research Program water quality data set comprises six sample periods within the years 1999-2000, and represents nine sample sites along the Lower Musselshell River study area.

Each of the following graphs represented by Figures 6, 7, 8, 10, 11, and 12 are comprised of nine raw data values representing each of the nine sample sites used in this study. The box plots group the site data based on the sample date they were obtained. The purpose of depicting the values as box plots is to show the large variation in concentrations between sites within a given sample date. The figures yield rough seasonal trends for each of the analyzed parameters. Note that the values are ordered by the month collected rather than the year.

Total Suspended Solids

Total suspended solids is the concentration of suspended materials, including organic matter and clays in the water column (Walling 1988). High total suspended solids values are typical for the Lower Musselshell River, but it is not understood what range of values represent naturally occurring levels for the Lower Musselshell River (Musselshell River Basin Water Management Study 1998 and Miller 1980).

Concentrations of total suspended solids vary within the study area. Concentrations of total suspended solids are affected by river flow, river velocity at the sample site, morphology of the river upstream of the sample site, river sediment bed load, substrate and bank composition above and adjacent to the sample site, and human and animal activities occurring in the watershed (Musselshell River Basin Water Management Study 1998). Typically the concentration values along the Musselshell River are affected by peak flow and recent rain events within the Musselshell River Watershed. The effects of recent rainfall events were observed on August 19, 1999 and July 20, 2000 (Fig. 6). Corresponding flows per sample date are shown in Figure 7.

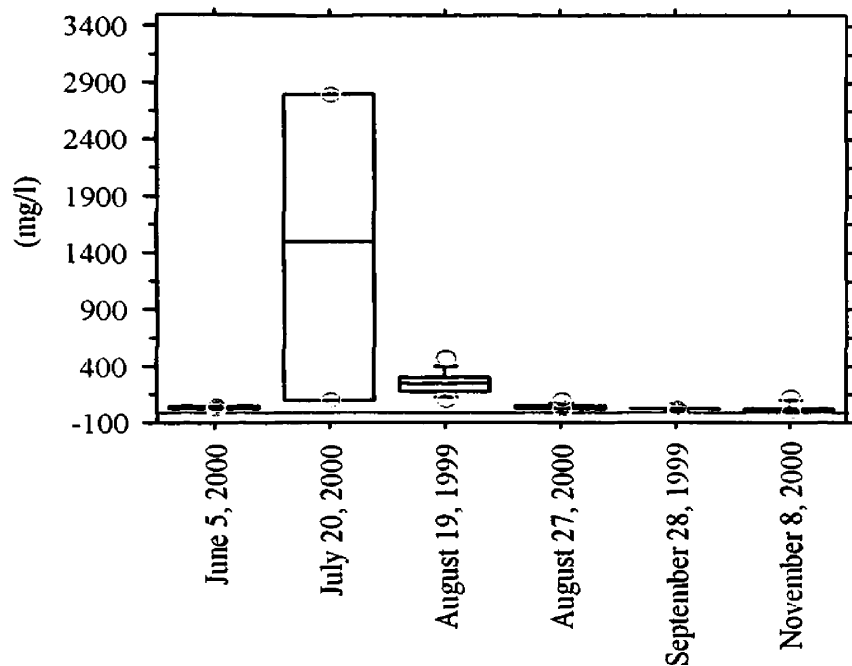


Figure 6. Box plot of concentration of total suspended solids per sample date.

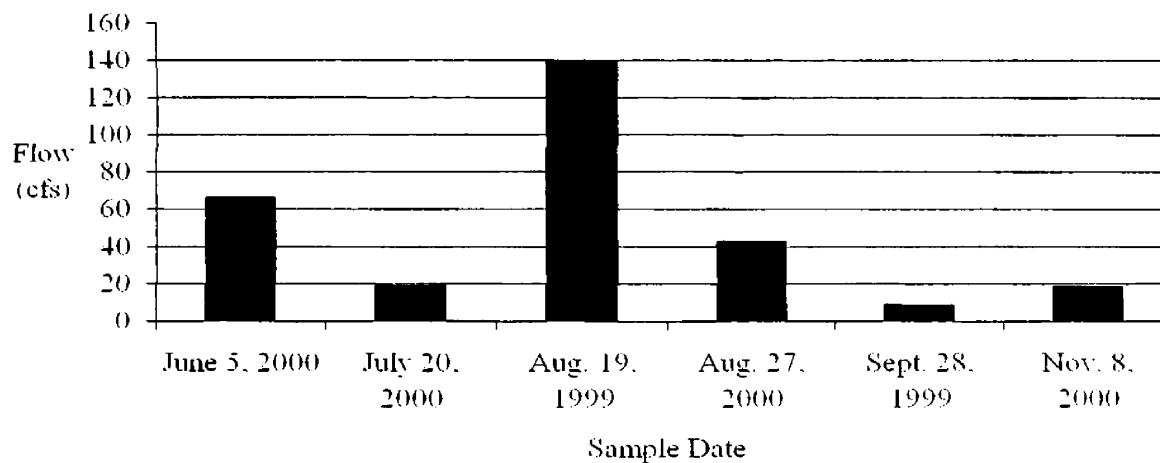


Figure 7. Average total flow per sample date measured at 9 sites on the Lower Musselshell River.

The average concentration of total suspended solids at the nine study sites on August 19, 1999 was 250 mg/l. This value relates to an average river flow of 139 cfs as a result of fall season thunderstorms near Roundup and Melstone and water releases from the Deadman's Basin Reservoir for downstream water users. The average concentration of

total suspended solids for July 20, 2000 was 1786 mg/l. This value corresponds to a local 100 year return interval rainfall event which occurred at Mosby, Montana on July 19, 2000, yielding an average river flow of 19 cfs. This event caused dramatic scouring of tributary coulees and creeks that feed the Lower Musselshell River. During the sample date July 20, 2000, irrigation withdrawals were observed at Site 7. Values for total suspended solids dropped from 2,800 mg/l to 96 mg/l and 92 mg/l at Site 8 and Site 9 respectively. This significant drop was due to a change in flow at the same sites from 25cfs to 10cfs respectively. The river velocity was greatly influenced by pooling at Site 8 and Site 9. The pooling allowed the sediments to settle out of the water column yielding a rapid decline in concentrations.

Other sample periods correspond to base flow conditions and irrigation return flow dominating the river flow (Fig. 6). Negative values on the y axis of the boxplots were generated by the graphing program for parameters with high variability and an average near zero.

Total Dissolved Solids

Total dissolved solids is a measure of mineral constituents dissolved from rock and soils. It includes all material that is in solution in the water column. High values for total dissolved solids are thought to be natural (naturally occurring levels not determined), due to natural and man-made saline seeps and underlying cretaceous shale formations such as the Bear Paw Shales.

Concentrations of total dissolved solids are affected by flow. As flow increases concentrations of total dissolved solids will decrease (Christensen and Pope 1997 and Rasmussen 1998). A relationship between total dissolved solids and flow could not be defined (Fig. 8), however the large USGS data set does make it possible to define a relationship (Fig. 9).

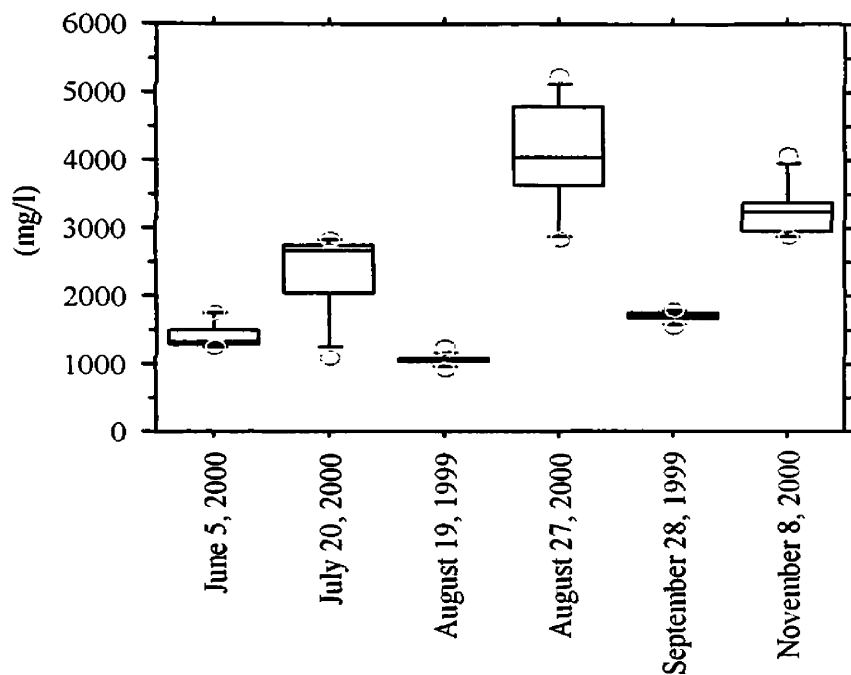


Figure 8. Box plot of concentration of total dissolved solids per sample date.

Concentrations of total dissolved solids are also related to season variations when groundwater inputs into the river are the greatest (Miller 1980). Natural saline seeps exist in this region and are found locally. Groundwater dissolves these natural salts and carries them into the surface water of the river (Miller 1980). Therefore, during baseflow periods there is a tendency for concentrations of total dissolved solids to be elevated above periods of equal or greater flow dominated by spring runoff and overland flow. For example, samples taken on August 19, 1999, average flow of 139 cfs, were dominated by overland flow from rainfall events, whereas samples taken on June 5, 2000, average flow of 66 cfs, were dominated by groundwater inputs (Fig. 8).

Data obtained from the U. S. Geological Survey gauging station at Mosby, Montana does show a strong relationship between total dissolved solids and flow (Fig. 9).

Concentrations of total dissolved solids decrease exponentially as flow increases. The transition point to a more linear relation is at approximately 300 cfs. This relationship holds true for each of the U. S. Geological Survey gauging stations along the entire

length of the Musselshell River. It is predicted that the relationship would hold true for all of the sites along the study area.

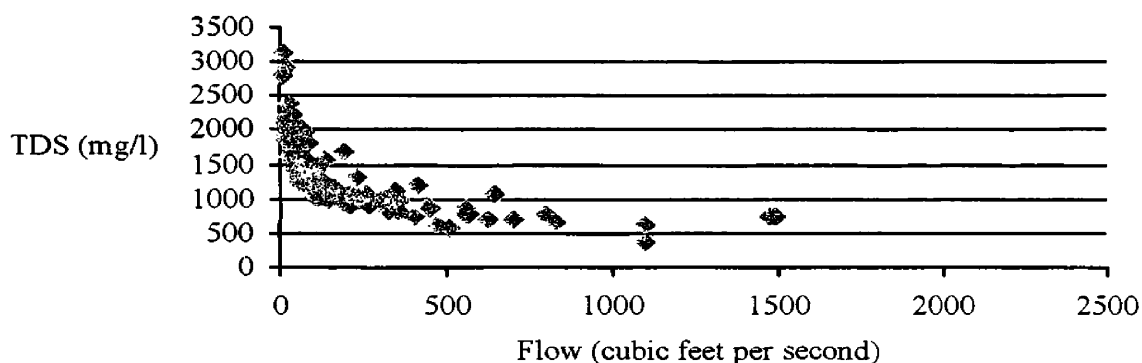


Figure 9. Curvilinear relationship of total dissolved solids (TDS) to flow at the Mosby Bridge USGS gauging station on the Lower Musselshell River 1979-1999.

Nutrients (Nitrates/Nitrites and Total Phosphorous)

Sources of nutrients within a river system can include fertilizers, municipal sewage waste water, animals wastes, and the break down of organics (Pionke and others 1999 and Christensen and Pope 1997). Nitrogen and phosphorous are important in plant growth, plant reproduction, and plant protein synthesis. High concentrations of phosphorous can lead to algal blooms which deplete soluble oxygen in the water column (Dent and Henry 1999 and Christensen and Pope 1997). The primary source of phosphorous in an unaltered non- agricultural river is leaf decomposition (Tiedeman and Higgins 1989). Phosphorous sources in altered systems may come from the dissolution of exposed soils and rock, wetland disturbance, or fertilizer applications.

Nitrogen fixing plants, such as alfalfa, which is a plant of choice for hay production on the river bottoms and uplands within the Musselshell River watershed, is a source of nitrogen to a river system. Other major sources may include municipal waste from sewage treatment plants, livestock, other animal wastes, and fertilizer applications. The nitrogen cycle can be a limiting component to a river system, but elevated levels usually have little to do with large algal blooms. Nitrate is the most readily used form of nitrogen by plants in the water column (Dent and Henry 1999 and Rasmussen 1998).

Concentrations of both nitrates/nitrites and total phosphorous follow a similar pattern of higher and lower values for each sample date (Fig. 10 and 11). Average values for nitrate never exceeded EPA drinking water standard of 10 ppm in the samples collected.

Phosphorous, as of yet, does not have an EPA standard.

Higher levels of both nutrient parameters were noted on August 19, 1999. These levels may be associated with overland flow due to rain events near Roundup and Melstone, Montana a few days earlier and may also correlate with periods of grazing in the lower section of the river along the riparian area. Livestock were present on some reaches of the study area during each sampling period.

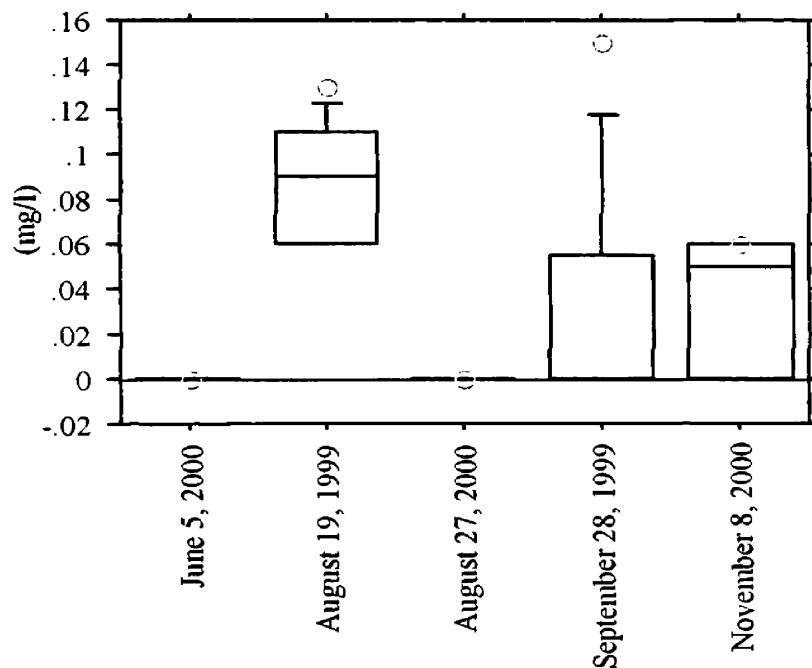


Figure 10. Box plot of the concentration of total nitrates/nitrites per sample date.

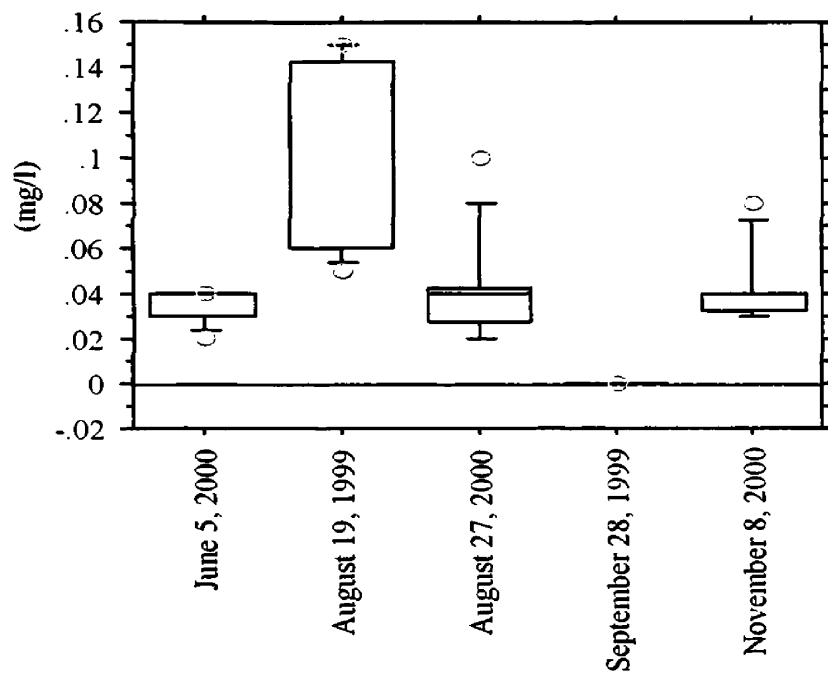


Figure 11. Box plot of the concentration of total phosphorous per sample date.

Nitrate/nitrite, total phosphorous, and fecal coliform samples were not taken for the July 20, 2000 sample period. The timing of sampling prevented them from making it to the lab for analysis within 72 hours and 24 hours respectively.

Fecal Coliform

Fecal coliform is a measure of concentrations of human and animal wastes within the water column. It is used as an indicator of the presence of pathogenic organisms in the water column.

Fecal coliform concentrations spiked during August sampling periods (Fig. 12). Similar spikes were observed in the nutrient data. Spikes in fecal coliform counts may be attributed to heavier than usual livestock use in river bottoms (Hardesty and Barrett 1994). Typically, livestock concentrate beyond the Musselshell valley due to the cooler temperatures and wind associated with the uplands. Lack of stock water in the uplands drove livestock and other animals into the valley along the river for water and shade.

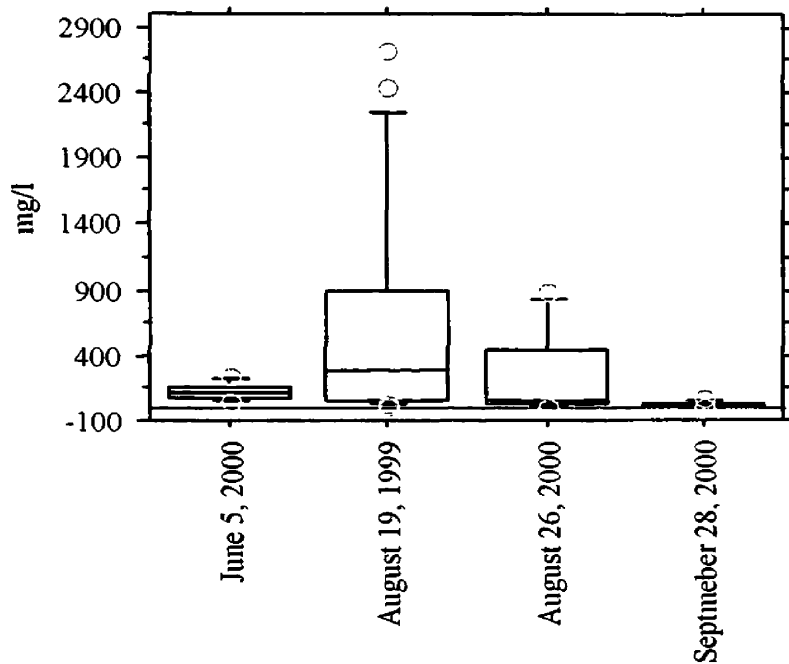


Figure 12 . Box plot of the fecal coliform count per sample date.

There are sporadic jumps in the fecal coliform counts on a given sample date from the upstream to the downstream end of the study area (Fig. 12). For the sample date August 19, 1999, fecal counts peaked at Site 4 with a concentration of 2,730/100 ml, dropped to 120/100 ml at Site 5 one mile downstream and peaked again at Site 7 at 2,450/100 ml and Site 8 at 1,740/100 ml. These spikes could be induced by a myriad of factors. Bottom sediment disturbance may have introduced more fecal coliform into the water column, livestock could have been defecating in the river just prior to sampling, or it could be sampling error. It is significant to note these values and realize they can exist. Beware that concentrations can change dramatically from site to site on any given sample day, especially during periods of low flow due to pooling, irrigation return flow, and evaporation. Each site is only representative of itself.

Periphyton

Periphyton assemblages are used in stream monitoring to evaluate the health of a river based on the distribution, density, and species composition of an assemblage per stream reach monitored. These assemblages can then be used to identify nutrient concerns and establish a general assessment of the health of a river (Plafkin and others 1989). As

nutrients are transported through a dynamic river system the nutrient can take on many chemical forms and be bound in substrates and biota. These different chemical forms and different binding mechanisms have different storage times in relation to each other and are released back into the surface water column at different rates and concentrations (Walling 1988). This variability in nutrient cycling may be assessable based on the distribution and composition of periphyton in a river. Periphyton are important to the ecology of river systems (Dent and Henry 1999 and Junk 1983). They contribute to primary production of a river and are influential in the cycling of nutrients in the water column (Junk 1983 and Hynes 1970).

According to our phycology consultant the Musselshell River sample's diatom diversity was good (Table 8). Diatom metrics indicated that all six sites on the river fully supported their aquatic life uses, with minor impairment due to elevated nutrients. Siltation index values in the Musselshell River were much lower than they were in similar streams, and indicated full support of uses for a prairie (C-3) stream. All sites showed low physical, chemical, or biological disturbance (Bahls 2000).

Table 8. Percent abundance of major diatom species and values of selected diatom association metrics for periphyton samples collected from the Lower Musselshell River in 1999.

Species/Metric	Reach					
(Pollution Tolerance Class)	Site 1	Site 2	Site 4	Site 5	Site 7	Site 9
<i>Cyclotella distinguenda</i> (2)	0.95	16.43	19.55	8.41	0.41	6.58
<i>Diploneis puella</i> (2)	14.76	9.42	9.16	4.21	4.08	5.7
<i>Epithemia adnata</i> (2)	3.1	0.97	0.5	6.54	11.02	1.54
<i>Epithemia sorex</i> (3)	0.24	0.99	3.5	14.08	2.41	
<i>Navicula durrenbergiana</i> (1)	0.24	1.93	5.2	12.38	0.82	1.32
Number of Cells Counted	210	207	202	214	245	228
Shannon Species Diversity	5.03	4.87	4.67	4.94	4.78	5.35
Pollution Index	2.02	1.93	1.82	1.92	2.25	1.78
Siltation Index	42.19	49.26	49.06	45.08	32.84	48.3
	3.1	0.48	4.46	5.14	7.14	0.44
Number of Species Counted	59	58	52	52	55	65
Percent Dominant Species	14.76	16.43	19.55	12.38	14.08	9.21
Percent Abnormal Cells	0	0.48	0	0	0	0.88
Percent Epithemiaceae	4.77	1.93	1.99	14.24	28.57	12.51
Similarity Index	53.11	68.75	52.44	50.68	4	2.84

Adapted from personal communication with (Bahls, 2000)

Evaluation of Historic Water Quality Data for the Mosby Bridge (Site 4)

Historic data for the Mosby Bridge was gathered by the U. S. Geological Survey, the Montana Department of Environmental Quality, and private contractors fulfilling grant research for the Montana Department of Environmental Quality. These data are being used in this thesis to help establish a better understanding of the trends and general characteristics of the water quality of the Lower Musselshell River. This data set helps to substantiate values produced from sampling throughout the present study.

The USGS is regarded as a credible data source for water quality, therefore it is assumed that USGS data has acceptable quality for the purpose used here

The following results are organized by the water quality parameter being analyzed and the subsequent types of analysis. The data represents sample values attained between 1972-1993 at Mosby, Montana U. S. Geological Survey Gauging Station, HUC 1004025.

River Flow and Local Rainfall

Flow of a river can have a variety of effects on concentrations and loads (mass per unit of time; tons/day) of water quality parameters (Eheart and Tornil 1999, Rasmussen 1998, and Christensen and Pope 1997). For example, concentrations of total suspended solids vary with an increase in flow because of the erosive behavior of a river at varying flows. At high flows a river is traveling at a high velocity and is carrying more water therefore has a greater capacity to erode river banks and carry sediment in suspension. At low flow less energy is available to erode river banks or carry sediment in suspension (Walling 1988). Total dissolved solids increase with decreased flow due to the effects of evaporation and lack of dilution, and is also a result of dissolution of soluble salts in ground water (Christensen and Pope 1997 and Miller 1980). Figure 13 shows the average monthly flow at the U. S. Geological Gauging Station at Mosby, Montana from 1974-1995. Each bar in the graph was calculated using the average daily flow for 1974-1995; the number of data points per bar is approximately $n = 600$.

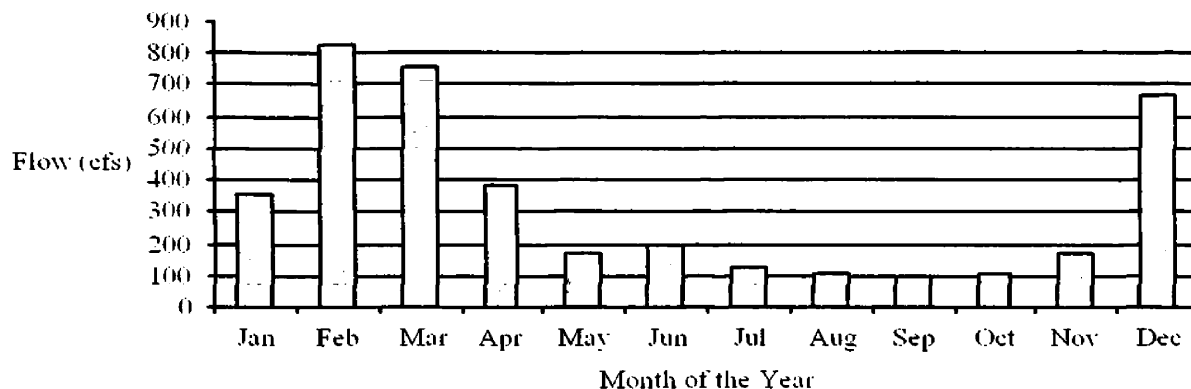


Figure 13 Average monthly flow at Mosby, Montana; 1974-1995, USGS (USGS 2001)

Localized rainfall events have a strong influence on nutrient and pathogen inputs to rivers and streams. Sources of nutrients and pathogens are the decomposition of plant material; leaves and stems, and animal wastes such as human sewage or animal dung (Henry and Dent 1999). Figure 14 shows the average monthly rainfall at Mosby Montana, from 1961-1990. Each bar represented in the graph was calculated from average daily rainfall from 1961-1990; n = 600.

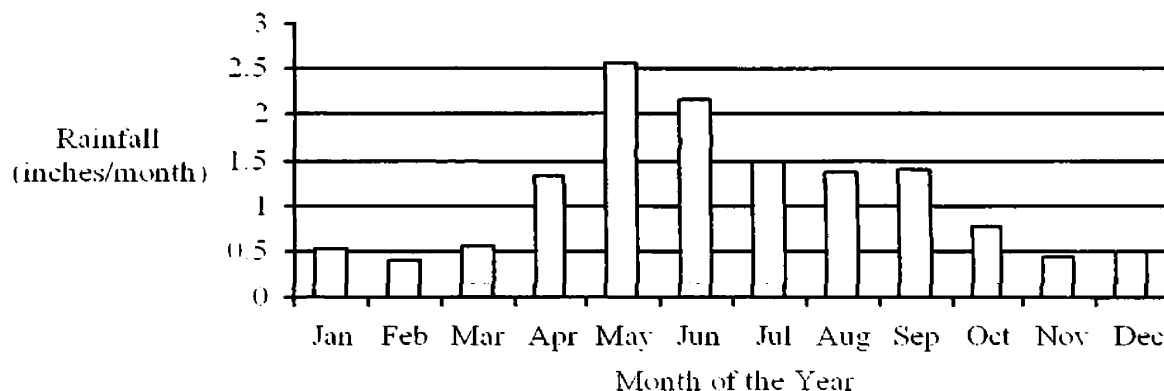


Figure 14 Average monthly rainfall at Mosby, Montana; 1961-1990, USGS (USGS 2001)

Spring rains are the largest contributor of moisture to the Mosby, Montana area and may have an effect on the concentrations of nutrients and pathogens in the water column.

Local spring rains have little effect on the hydrology of the Lower Musselshell River. Flow peaks at Mosby, Montana in February and March. These peaks in flow are a result of snowmelt in the headwaters of the Musselshell River; Big belt Mountains, Big Snowy Mountains, and the Crazy Mountains.

Total Suspended Solids

Total suspended solids appear to follow a seasonal pattern which is most likely influenced by rainfall in May and June. Box plots were used to analyze each parameter by month. Notable features of the box plot are the seasonal trend of total suspended solids concentrations and the peak values indicated by circles on the extremes of the box plots (Fig. 15). September shows the greatest departure from the median, 14,100 mg/l. This value is a response to a major rain event on the adjacent landscape. This assertion is similar to that made for the total suspended solids value of 17,100 mg/l on July, 20, 2000 (Riparian and Wetland Research Program Data) also occurring just after a local rain event. Spikes of total suspended solids during the months of August and September are a result of large local rain events. Environmental Quality Incentives Program improvement in cattle management and installation of riparian enclosures may yield reductions in total suspended solids in the water column during August and September. Increased plant diversity and density will improve soil cover, reduce upland soil erosion and help stabilize erodible stream banks (Skovlin 1984).

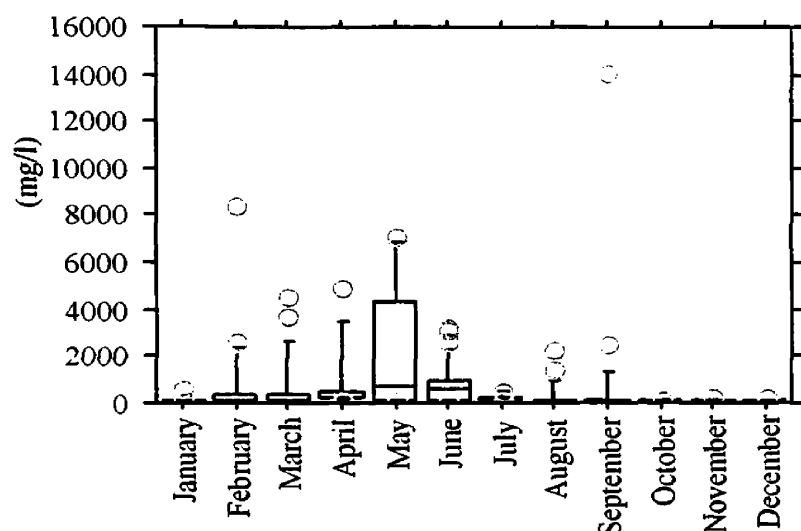


Figure 15. Box plot of concentrations of total suspended solids, 1974-1992

The total number of samples representing each month, for the period 1974-1992, shown in Figure 15 range from 8 in July to 32 in June (Table 9).

Table 9. Number of samples taken at Mosby, MT USGS station per month from 1974-1992; representing Figure 15, USGS (USGS 2001)

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
n =	9	16	20	11	15	32	8	19	24	9	14	14

A regression plot representing total suspended solids gathered in a time continuum from 1974-1992 at the Mosby station shows a statistically significant trend, $R^2 = 0.4$ (Fig. 16). This result may be due to the same trend in flow, decreasing peak flows, base flows, and rain events from 1974 to 1992. This graph is comprised of 191 samples. It is a fairly robust depiction of the possible values and trends of this parameter over time and could be used with high certainty in comparing future values and trends. The number of samples taken during each sample year from 1974-1992 increases from 3 in 1974 to 19 in 1991.

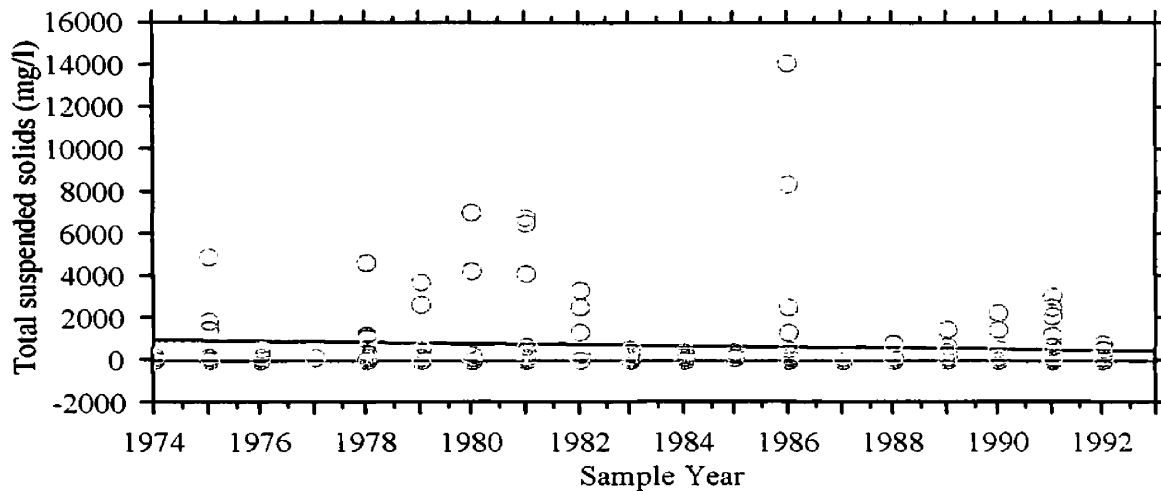


Figure 16. Regression display of total suspended solids versus sample year; 1974-1992

Total Nitrogen and Nitrates/Nitrites

The displayed data for total nitrogen depict a statistically significant seasonal trend in concentrations, $R^2 = 0.390$ (Fig. 17). Higher than average concentrations tend to be found from February to June. The months from February to June coincide with snowmelt and spring rains in the Upper and Lower Musselshell River basin, respectively. Higher total nitrogen concentrations are often found during periods of peak flow and rain events which are the largest contributors of nitrogen to a river system (Dent and Henry 1999 and Pionke and others 1999).

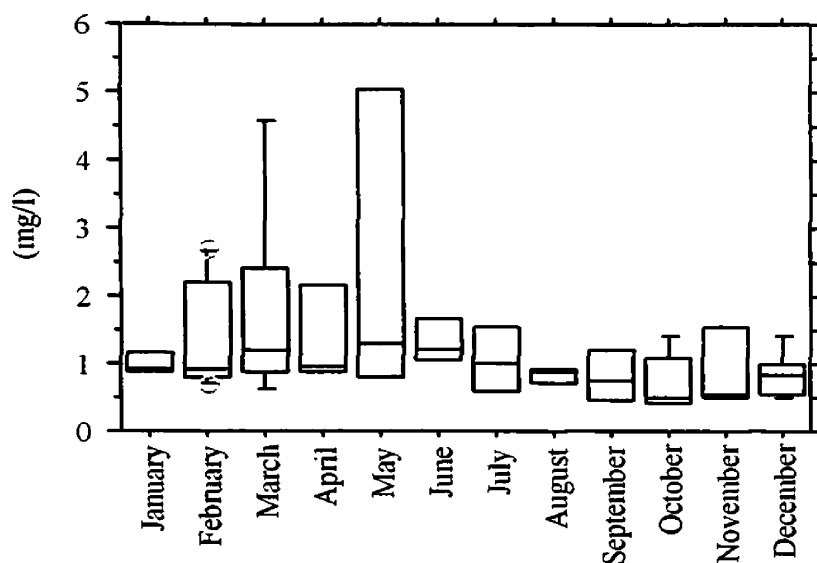


Figure 17. Box plot of concentrations of total nitrogen; 1974-1981

Nitrates/nitrites depict an opposite seasonal trend from the total nitrogen data (Fig. 18). Peaks occur in the fall and winter months with depressions in the spring and summer due to the increased temperatures and summer growth of aquatic and terrestrial plants. Nitrates and nitrites are the most available forms of nitrogen for plant and algae uptake during the growing season.

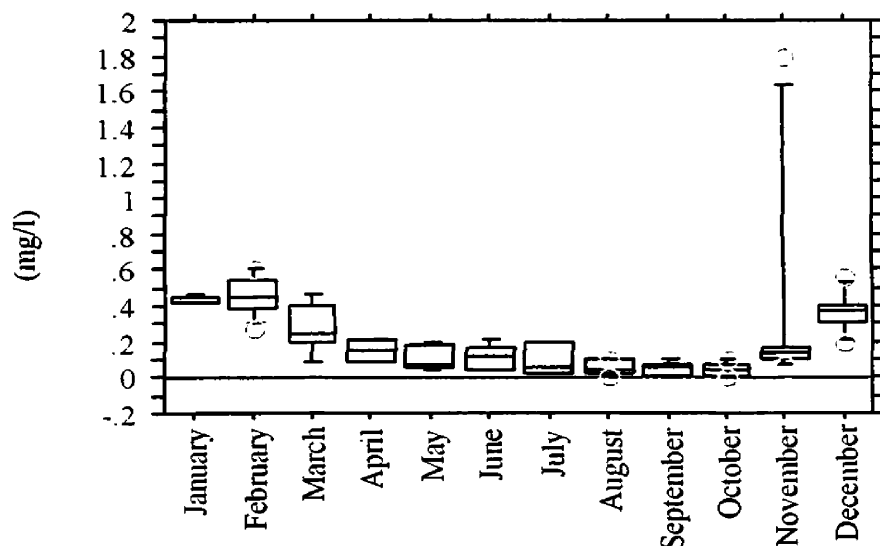


Figure 18. Box plot of concentrations of nitrates/nitrites; 1974-1992

Sampling frequency distributions of the nitrogen data exhibit a rather sporadic sampling period from 1974-1992. Maximum counts for any one month over the time period was 8 samples with a minimum of 3 in July, which is a period of fairly high total nitrogen concentrations and low nitrate/nitrite concentrations (Table 10).

Table 10. Number of samples taken per month from 1974-1992 at the USGS Mosby, MT station on the Lower Musselshell River; representing Figures 17 and 18.

Month	Jan	Feb	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
NO/NO n=	5	8	5	4	5	5	3	6	5	6	6	7
TKN n=	4	6	5	4	4	3	3	4	4	5	4	5

Regression analysis for total nitrogen depicts an increasing trend from 1974-1981 (Fig. 19). Nitrates/nitrites show no trend at all for the periods of sampling. This is a good indication that no net change of nitrogen inputs have occurred above the Mosby Bridge station. The number of samples collected in any one year from 1974-1981 ranged from 3 samples in 1974 to 11 samples in 1979.

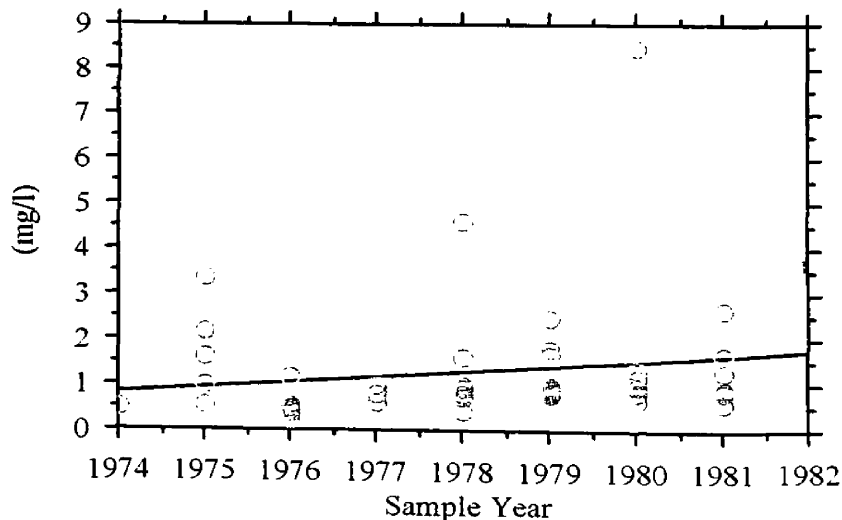


Figure 19. Regression plot for total nitrogen; 1974-1981

Total phosphorous

Phosphorous is a natural element found in the earth's crust. It is essential to life and found in all organic matter, hence it is released into the water and soil by the decomposition of detritus and sewage (Pionke and others 1999). Total phosphorous concentrations in the Lower Musselshell River follow a similar seasonal pattern to that of total nitrogen. Peaks tend to occur in the early spring which is correlated to periods of high overland flow from spring rains and snow melt (Fig. 20). Peaks in total phosphorous concentrations occurred as outliers within the months of August and September. Both of these months relate to typical high intensity low duration localized thunderstorms that erode and transport surface soils and incorporate sediments, organic matter, detritus, and feces into the water column.

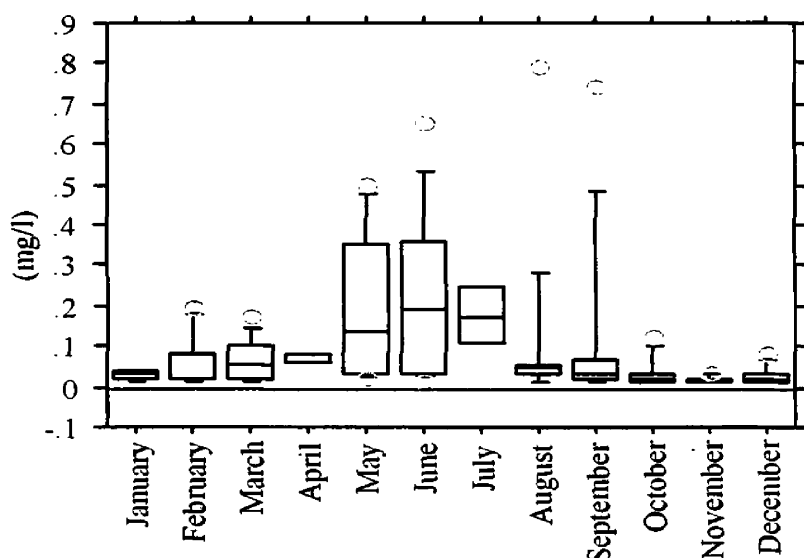


Figure 20. Box plot of concentrations of total phosphorous; 1974-1993

It is important to note that only three samples were taken over the entire sampling period, 1974-1993, for the month of April and the month of July (Table 11). These are key transition periods between winter depressions and spring peaks, respectively. The limited number of samples may have an effect on the quality of the data for those two months.

Table 11. Number of samples taken per month from 1974-1993 at the USGS Mosby, MT station on the Lower Musselshell River; representing Figure 20

Month	Jan	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
n =	5	12	9	3	8	12	3	12	9	7	12	10

From 1974 to 1994 total phosphorous levels show a downward trend (Fig. 21). This trend is opposite of the trend seen with total nitrogen concentrations in Figure 19. A similar downward trend is observed for flow for the sampling period 1974-1993. Although, regression analysis does not show a strong correlation between total phosphorous concentrations and flow, $R^2 = 0.395$, a connection between the two trends does seem apparent. Changes in cattle management and irrigation efficiencies may have been a factor in the downward trend of concentrations. Frequency distributions for total phosphorous show a decrease in sampling pressure for a continuous period from 1974-1993. The number of samples ranged from 7 samples in 1993 to 21 samples in 1978.

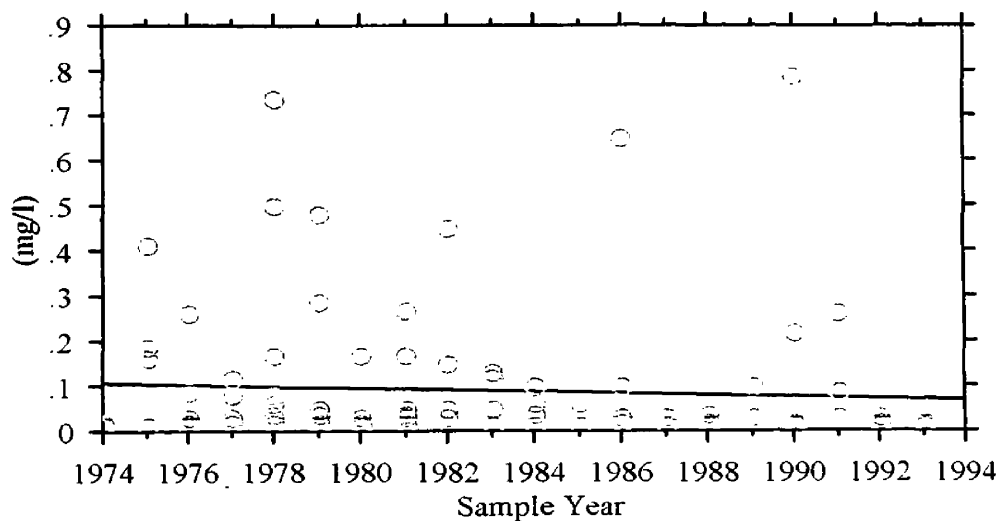


Figure 21. Regression plot of total phosphorous; 1974-1993

Fecal coliform

Fecal coliform is an indicator of animal use levels along the riparian corridor and in the main river channel. Fecal coliform counts can be affected by the river flow and overland flow caused by melt water and rain events. Monthly sampling for fecal coliform shows

seasonal trends similar to the trends seen in preceding analyses of other particulate parameters (Fig. 22).

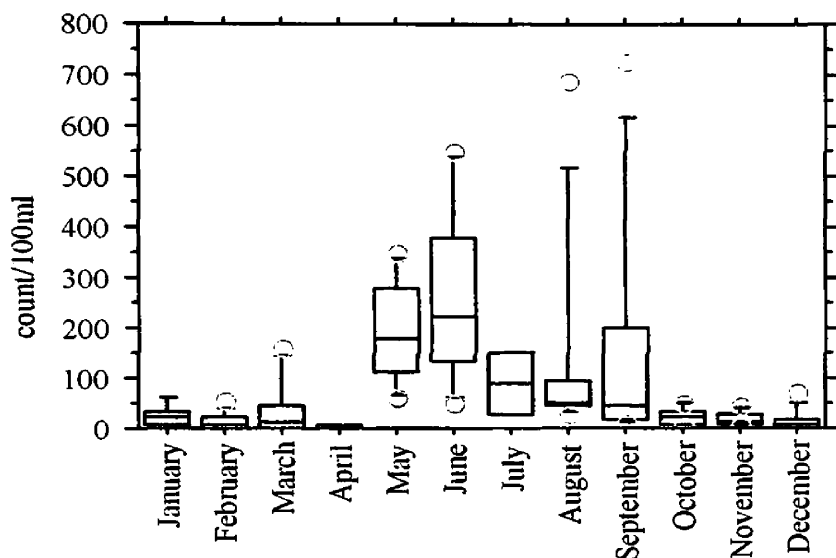


Figure 22. Box plot for fecal coliform count; 1976-1993

Fecal coliform can be trapped in bed load sediments and upland soils and be held in suspension in the water column (Walling 1988). Therefore, fecal coliform is mobile during scouring events and during periods of overland flow. These types of events are common during May and June snowmelt periods and in August and September during high intensity low duration rainfall events. Fecal coliform counts ranged from 1/100 ml in the winter and early spring to 730/100 ml in the late summer and fall. Fecal coliform concentrations of 2,730/100 ml, 2,450/100 ml, and 1,740/100ml were observed in 1999-2000 above and below the Mosby Bridge station during this study.

The fewest samples collected for any month from 1976-1993 was in April and the most total samples in February and March (Table 12).

Table 12. Number of samples taken per month from 1976-1993; representing Figure 22

Month	Jan	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec
n =	5	11	11	3	7	8	7	8	8	6	10	9

Figure 23 is a regression plot of fecal coliform counts over time. There is a statistically significant trend in counts from 1976-1993. This upward trend could be due to increased livestock and ungulate pressures along the riparian area and in the river. Other influences may be increased human effluent entering the river from developing communities within the Lower Musselshell River Watershed. The frequency of sampling intensity from 1976-1993 indicate an array of intensities and may be a factor in the generalized trend shown in Figure 23. There is variation in the number of samples taken per year, with 22 samples taken in 1978 and 1979 and four samples taken in 1981, 1982, 1986, and 1987.

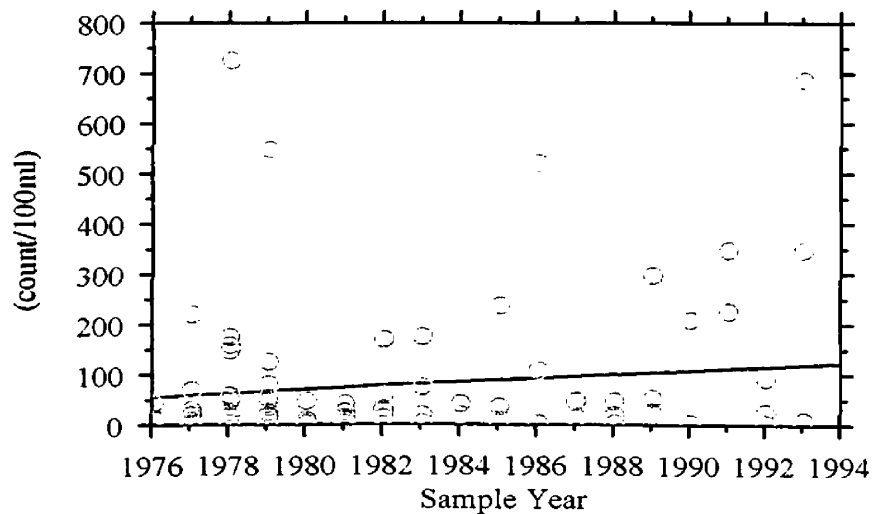


Figure 23. Regression plot for fecal coliform count; 1976-1993

CONCLUSIONS

Conclusions are organized based on the objectives and questions set out at the beginning of this thesis. Those objectives are restated here to remind the reader.

Objectives

- A) To assess/evaluate the validity and practicality of the Lower Musselshell River monitoring plan within the context of the following questions:
- a) Is the monitoring plan statistically rigorous? Is it capable of identifying statistically significant spatial and temporal trends?
 - b) Is the monitoring plan economically feasible?
 - c) Is the monitoring plan repeatable by other people doing follow-up monitoring?

a) Is the monitoring plan statistically rigorous? Is it capable of identifying statistically significant spatial and temporal trends?

The monitoring plan refers to the water quality methods described in the Methods section of this thesis devised by the author and Riparian and Wetland Research Program personnel.

With only six sample periods representing each of the nine sample sites within the study area, it is not plausible, in this study, to identify statistically significant spatial and temporal trends in water quality within the study area at the present time. Other studies evaluating similar criteria and parameters suggest that this type of monitoring scheme is an acceptable and readily chosen means for determining spatial and temporal trends in water quality (Pionke and others 1998, Rasmussen 1998, Christensen and Pope 1997, and Tiedemann and Higgins 1989).

Rasmussen (1998) used an upstream/downstream sampling design to assess the current conditions and possible methods for anticipating water quality effects from storm run off and changes in land use. Using an upstream/downstream monitoring scheme he was able to show a statistically significant increase in total dissolved solids at low flow and show

that storm runoff had the greatest capacity for loading of the water column with different water quality constituents.

Pionke and others (1999) studied a 7.3 km² watershed in an agricultural hill land in Pennsylvania to decipher the effect of season on nutrient patterns. They analyzed a 12 year period of record. A watershed analysis was used to determine the climatic conditions of each season, biomass productivity, and land use activities. The analysis included a differentiation between base flow and over flow and the effect of these two water patterns on nutrient concentrations. Samples were taken at different points within the watershed comprising an upstream/ downstream assessment. Flow and seasonal trends of nutrients were used to determine sampling intensities and sample periods. Results from this study produced statistically significant trends in seasonal nutrient patterns.

Grabow and others (1999) note that upstream/ downstream monitoring designs are common to water quality studies. These types of monitoring plans are used in conjunction with a before/after design to monitor the effects of pre-treatment and post-treatment conditions within a watershed undergoing management changes. Both designs require that water quality samples be taken before and after treatment periods at sample sites upstream and downstream of the treatment area. Sample sites in an upstream/downstream design are taken at concurrent times and are therefore considered paired spatial data. This distinction is important in running statistical tests to detect statistically significant trends or changes in water quality due to management changes. Hydrologic and meteorological conditions must be similar in order for the data to be considered concurrent or paired data. This distinction is important in the context of the Lower Musselshell River and other rivers, which may experience extended periods of low flow or periods of extended irrigation withdrawal and subsequent irrigation return. Under these circumstances the hydrology of the river system is not similar throughout the study area due to differences in hydrologic conditions at upstream and downstream sites. Groundwater/surface water interactions which dominate surface water quality during low flow periods and irrigation periods may also influence the similarity of hydrologic conditions at each sample site.

Localized rain events can also be very site specific which would create plausible errors in analysis if the data were assumed to be paired.

Results from six sample periods conducted during the Riparian and Wetland Research Program study exhibit significant changes in each water quality parameter measured from site to site. Table 13 depicts the concentrations of each water quality parameter for the sample period August 19, 1999. The reason for these changes in water quality concentrations is unknown. There are multiple compounding factors which contribute to the difference in concentrations between sites. Flow has a strong influence on the concentrations of each parameter (Pionke and others 1999). Flow varies within the study area from site to site. This variation in flow is due primarily to irrigation withdrawals and return flows which vary from site to site. Variations in flow may also be due to surface water/groundwater interactions contributing to effluent and influent reaches along the river (Sharp 1988). This latter idea would require intensive monitoring of groundwater /surface water interactions along the entire study area. This type of monitoring would be very time consuming and is not recommended within the scope of this project or the final watershed restoration plan being written for the Lower Musselshell River.

Table 13. Concentrations of measured water quality parameters for the sample date August 19, 1999 collected from water quality sites on the Lower Musselshell River.

Site	Flow	Fecal Coliform	Nitrate/Nitrite	Tot. Phosphorus	Tot. dissolved solids	Tot. suspended solids
ID	cfs	(Count/100mL)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
1	183	630	0.13	0.13	902	271
2	144	632	0.06	0.05	1050	106
3	140	234	0.07	0.06	1070	164
4	86	2730	0.1	0.06	1050	253
5	150	120	0.06	0.06	1050	173
6	145	200	0.06	0.06	1050	477
7	79	2450	0.11	0.15	1020	310
8	155	1740	0.11	0.15	1120	309
9	157	900	0.09	0.14	1230	189

An upstream/ downstream comparison of Site 1 and Site 9 is shown in Figure 24. The bar chart depicts the proportion of the average concentration of six sample periods for each

measured parameter entering the study area compared to the proportion of the average concentration of each measured parameter leaving the study area.

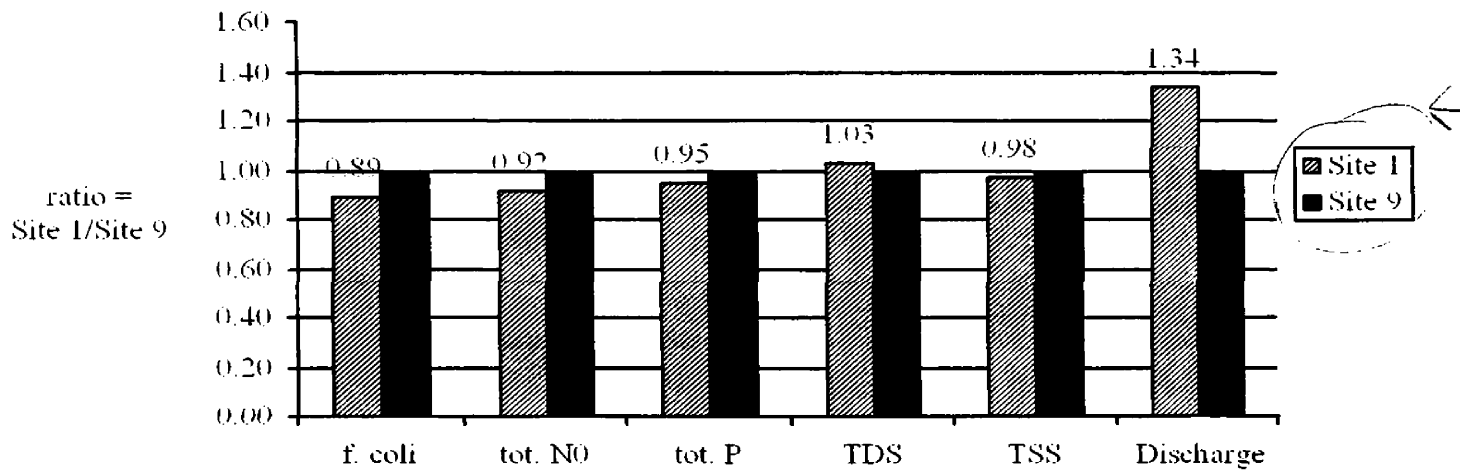


Figure 24. Upstream/ downstream comparison of Site 1 to Site 9 for average concentrations of fecal coliform (f. coli), nitrates/nitrites (tot. NO), total phosphorous (tot. P), total dissolved solids (TDS), total suspended solids (TSS), and flow (discharge). The numbers are the ratio of Site 1 to Site 9 concentrations.

The apparent drop in concentrations for four of the parameters could be due to pooling, groundwater/surface water interactions, irrigation withdrawals, evaporation from surface waters and evapotranspiration via plant growth. Water from rivers moves laterally and vertically through a heterogeneous distribution of sediments (Sharp 1988). River water also saturates and exchanges with heterogeneous deposits of sediments which are variable in distribution along the river channel bottom. In both cases the surface water is exchanging nutrients and water over a continuum. The nutrients which follow this exchange are then transformed and redistributed in time and space differently than as they are in the surface water (Triska 1989 and Velett and others 1993). Sample sites are relatively isolated at low flow. Sample values should only be used to represent the site from which they were obtained. A conservative tracer of some sort would have to be introduced into the river system in order to evaluate against losses. At high flows it is more plausible that water entering the study area is most of the same water leaving the study area. High flows during non-irrigation periods will produce concurrent paired data that would be useful for comparative analysis. Low flow periods will produce meaningful

results but may not be used for paired comparative analysis due to differences in hydrologic conditions between sample sites.

Table 14 shows the concentrations of water quality parameters for the sample period August 27, 2000. There was no surface flow within the study area during this period. Notice fecal coliform concentrations vary over two orders of magnitude between sample sites.

Table 14. Concentrations of fecal coliform, nitrate/nitrite, total phosphorous, total dissolved solids, and total suspended sediments for sample Sites 1-9 corresponding to pooled water samples; August 27, 2000

Site ID	Fecal Coliform (Count/100mL)	Nitrate/Nitrite (mg/L)	Tot. Phosphorus (mg/L)	Tot. dissolved solids (mg/L)	Tot. suspended solids (mg/L)
1	30	<0.05	0.1	3860	91
2	20	<0.05	0.03	4040	31
3	60	<0.05	0.04	4030	28
4	10	<0.05	0.03	5270	22
5	80	<0.05	0.04	4870	32
6	340	<0.05	0.05	2900	45
7	740	<0.05	0.04	2830	36
8	7790	<0.05	0.02	4700	16
9	880	<0.05	0.02	4760	17

Total suspended solids are not conservative in relation to flow. For example, Figure 25 depicts the dramatic effect of irrigation withdrawals between sites 7 and 8 on total suspended solids for the sample date July 20, 2000. Samples were not collected at Sites 1, 4, or 5. The average concentration of total suspended solids for July 20, 2000 was 1786 mg/l. This value corresponds to a local 100 year return interval rainfall event which occurred at Mosby, Montana on July 19, 2000, yielding an average river flow of 19 cfs. This event caused dramatic scouring of tributary coulees and creeks that feed the Lower Musselshell River. During the sample date July 20, 2000, irrigation withdrawals were observed at Site 7. Values for total suspended solids dropped from 2,800 mg/l to 96 mg/l and 92 mg/l at Site 8 and Site 9 respectively. This significant drop was due to a change in flow at the same sites from 25 cfs to 10 cfs respectively. The river velocity was greatly influenced by pooling at Site 8 and Site 9. The pooling allowed the sediments to settle out of the water column yielding a rapid decline in concentrations.

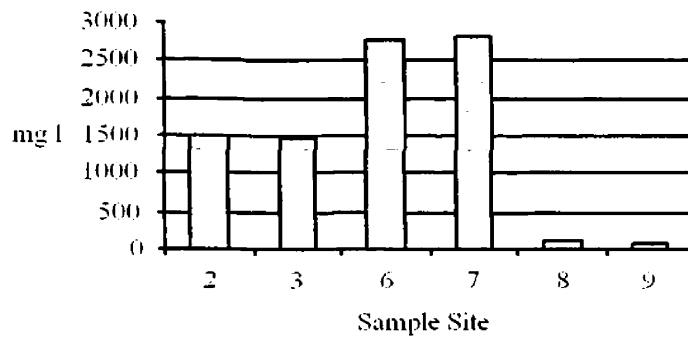


Figure 25. Concentrations of total suspended solids on July 20, 2000 at sample sites 2, 3, 6, 7, 8, and 9 on the Lower Musselshell River.

b) Is the monitoring plan economically feasible?

It is unknown whether the Lower Musselshell River monitoring plan is economically feasible for long term monitoring of the river or for other watersheds and water body segments similar in size to the Lower Musselshell River. With the current and proposed budget cuts of many state and federal agencies involved in sponsoring watershed and water quality monitoring programs in the State of Montana, it is foreseeable that funding will not be available to continue monitoring on the Lower Musselshell River at the intensity pursued in this study.

The total cost of sampling is primarily a function of time; the number of personnel required to perform necessary tasks and the amount of time required to monitor, evaluate, and summarize data. Variable lab costs related to water quality sample analysis must also be calculated into the total project cost (Sheldon 1983).

A question that must be asked by the organization involved in the monitoring and the organization(s) interested in the data is, how precise the data needs to be. Cost reductions in the number of sample sites being sampled can increase the amount of samples taken from fewer sites increasing the precision of the data obtained from those sites. Precision refers to the consistency of the data for a particular site. Sampling multiple sites can be cost prohibitive. Sampling constraints should be applied to ecological studies prior to

monitoring implementation to avoid time and resource limitations during monitoring implementation. Lack of foresight may result in an expensive and inadequate set of results that do not represent the original objectives (Sheldon 1983).

In order to evaluate the economic feasibility of the Lower Musselshell River monitoring plan for future monitoring a cost analysis must be made. The critical costs to address are:

Travel—to and from the sample sites and between sample sites

Personnel—the number of personnel required to perform each task in the field and in the office

Time—travel, sampling per site, data analysis requirements, and summary reports and presentations of the data

Lab analysis—number of parameters being sampled, mailing fees and packaging costs

Office and Shop costs—sampling equipment, computer software equipment for analysis, expenditures related to the project

This is not an exhaustive list but may be used as a template to formulate budget needs. After a formal budget has been prepared adjustments should first be made to the number of sample sites being measured. This will reduce travel and personnel time requirements and will reduce lab costs associated with lab analysis. The objectives of the monitoring must be clearly stated and then evaluated in the context of the monitoring plan.

The Lower Musselshell River Monitoring Plan devised by the Riparian and Wetland Research Program is designed to evaluate the effectiveness of management changes occurring within the watershed. Sample sites are paired in an up and downstream scheme in order to capture changes in water quality due to changes in management. If sample sites are removed they should be removed in pairs. The amount of available funds will determine the feasibility of the monitoring plan for future monitoring.

c) Is the monitoring plan repeatable by other people doing follow-up monitoring?

The monitoring plan is repeatable. The methods and materials defined in the methods section of this thesis in conjunction with protocols referenced in the methods section of this thesis are sufficient to direct other researchers in continuing this monitoring.

Training workshops sponsored by agency personnel and other trained professionals are effective in teaching public citizens the necessary skills to perform sampling.

Sample sites have been monumented with rebar and identified on maps with accompanying photos of the sample site. Sites can be located easily and are accessible on foot with minimal walking on relatively even terrain.

Objective

B) Describe the seasonal variation for total dissolved solids, total suspended solids, total phosphorous, total nitrogen, nitrates/nitrites, and fecal coliform concentrations for the Lower Musselshell River.

- a) Are there patterns in the variation?
- b) What are the monthly maximums, minimums, and averages?
- c) Can the Mosby USGS Gauging station be used to describe the seasonal variation for total dissolved solids, total suspended sediments, total phosphorous, total nitrogen, nitrates/nitrites, and fecal coliform concentrations for the entire Lower Musselshell River?

a) Are there patterns in the seasonal variation for total dissolved solids, total suspended solids, total phosphorous, total nitrogen, nitrates/nitrites, and fecal coliform concentrations for the Lower Musselshell River.

Definitive seasonal patterns exist for total dissolved solids, total suspended solids, total phosphorous, total nitrogen, nitrates/nitrites, and fecal coliform concentrations for the Lower Musselshell River.

Total suspended solids, total phosphorous, total nitrogen, and fecal coliform concentrations consistently show the highest average concentrations in May and June. May and June coincide with peak periods of rainfall at Mosby, Montana. Rainfall produces overland flow which can contribute water quality constituents including sediment and nutrients in the form of leaf matter and residual fertilizers from agricultural fields (Pionke and others 1999 and Tiedemann and Higgins 1989). Peaks in concentrations of total suspended solids, total phosphorous, total nitrogen, and fecal coliform also occur in August and September. August and September coincide with high intensity low duration rainfall events that produce heavy overland flow and scouring of tributaries and coulees, which flow into the Musselshell River. An example of this type of event was seen in July 2000 after a 100 year return interval rainfall event occurred at Mosby, Montana. Concentrations of total suspended solids increased from approximately 60 mg/l to approximately 17,000 mg/l with an average of 3,640 mg/l calculated from five sites within the study area.

Flow at Mosby, Montana peaks in February and March just after the break up of ice sheets in the river. Concentrations of each of the parameters measured begin to increase at this time but do not peak until May and June. The source of water for the peak flows at Mosby, Montana are from the headwaters and surrounding uplands within the watershed. Localized overland flow probably contributes very little water to the total river flow. Therefore, the river flow is dominated by headwater area runoff which travels more than 480 km (300 miles) before it reaches Mosby, Montana and dominated by subsurface water sources which contribute relatively clean water to the river. This combination of sources probably contributes to low concentration of water quality constituents relative to periods of localized long duration or high intensity rainfall. Most Eastern Montana rivers will naturally peak in May and June, but due to heavy irrigation pressures and reservoir demands it is likely that irrigation water use which peaks in April and May has an impact on the contribution of meltwater being received at Mosby, Montana (Musselshell River Basin Water Management Study 1998). This change in the hydrology of the area may influence the timing and concentrations of total suspended solids, total phosphorous, total nitrogen, and fecal coliform (Ponce and Lindquist 1990).

The seasonal pattern of total dissolved solids and nitrates/ nitrites are unique. The concentration of total dissolved solids is primarily driven by flow; it is an inverse relationship (Christensen and Pope 1997 and Miller 1980). As flow decreases the concentration of total dissolved solids increases and vice versa.

Nitrates/nitrites concentrations are influenced by plant growth and photosynthesis. Concentrations are the highest in the fall and winter months when plants and algae are dormant (Stanford 1998 and Hynes 1970). Concentrations decrease beginning in February and continue to decline until August. The lowest concentrations are typically measured in May and June which are periods of peak growth and production by plants along the riparian corridor and algae and macrophytic vegetation occurring in the water column.

b) What are the monthly maximums, minimums, and averages?

Table 15 shows the monthly maximums and minimums for the historic water quality data obtained from the Montana Department of Environmental Quality and the U. S. Geological Survey. The number of samples taken and the number of years of monitoring varies by parameter.

Table 15. Maximum and minimum concentrations for total suspended solids (TSS), total dissolved solids (TDS), nitrate/nitrite, total nitrogen, total phosphorous, and fecal coliform; historic water quality data 1974-1993

Water Quality Parameter	TSS	TDS	Nitrate/ Nitrite	Total Nitrogen	Total Phosphorous	Fecal Coliform
Number of Samples (n =)	191	225	79	65	102	93
Minimum Concentration	13 mg/l	335 mg/l	0.0 mg/l	0.22 mg/l	0.010 mg/l	1 count/ 100 ml
Maximum Concentration	14,100 mg/l	3,200 mg/l	1.8 mg/l	8.5 mg/l	0.79 mg/l	730 count / 100 ml

Table 16 shows the minimum and maximum concentrations of water quality parameters measured by the Riparian and Wetland Research Program (RWRP) from 1999-2000. The

data represents all nine water quality sampling sites within the Lower Musselshell River Study.

Table 16. Maximum and minimum concentrations for total suspended solids (TSS), total dissolved solids (TDS), nitrate/nitrite, total phosphorous, and fecal coliform; RWRP data from 1999-2000

Water Quality Parameter	TSS	TDS	Nitrate/ Nitrite	Total Phosphorous	Fecal Coliform
Number of Samples (n =)	54	54	45	45	36
Minimum Concentration	10 mg/l	902 mg/l	0.02 mg/l	0.010 mg/l	3 count/ 100 ml
Maximum Concentration	17,100 mg/l	2,870 mg/l	0.15 mg/l	0.15 mg/l	7,790 count / 100 ml

Both data sets in Tables 15 and 16 depict a large range of values which are possible within any given year of sampling. It is important to note the large range of values possible for concentrations of each parameter when determining the effects of management changes on the landscape. Long term sampling will be the most accurate way of determining the effects of management changes and land use changes in water quality.

c) Can the Mosby USGS Gauging station be used to effectively describe the seasonal variation for total dissolved solids, total suspended solids, total phosphorous, nitrates/nitrites, fecal coliform, and periphyton measurements for the entire Lower Musselshell River.

The Mosby Bridge USGS gauging station (Site 4) could be used to describe the seasonal variation in water quality for the entire Lower Musselshell River. Figure 26 and 27 depict comparisons of Historic data per month; 1974-1993, to data collected in this study per month; 1999-2000 for fecal coliform and total suspended solids.

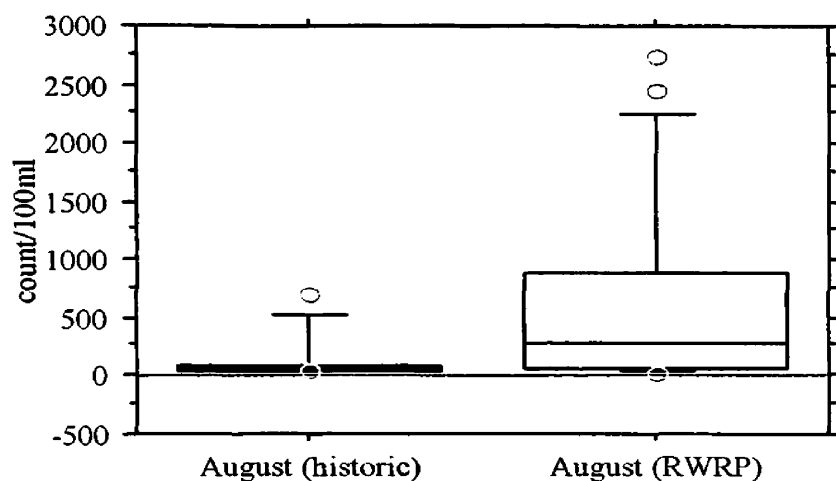


Figure 26. Comparison of fecal coliform counts from August historic water quality data taken at Site 4 ($n = 8$) to RWRP data taken at 9 sample sites within the study area for two sample periods in August ($n = 18$)

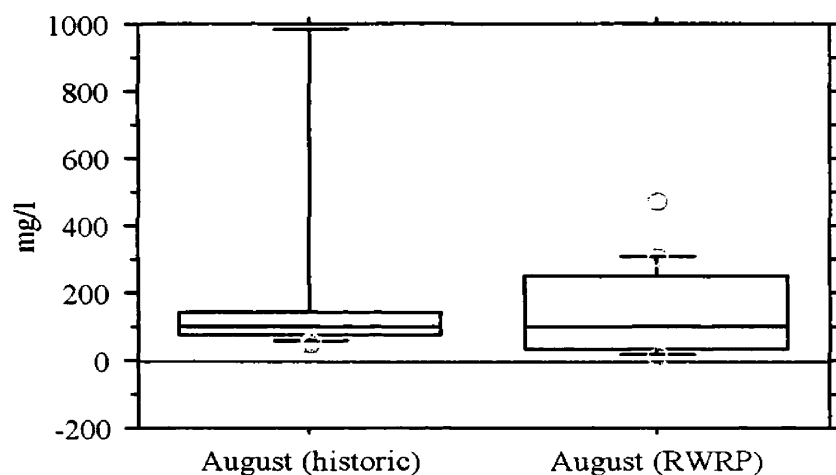


Figure 27. Comparison of total suspended solids concentrations for August historic water quality data ($n = 19$) to RWRP data representing 9 sample sites within the study area for two sample periods in August ($n = 18$)

I believe that the Mosby Bridge (Site 4) water quality samples are representative of the entire Lower Musselshell River study area. It is hypothesized that the Site 4 data could be used to describe the water quality of the entire study area. An ANOVA F-test was used to determine if this hypothesis is true or false.

Table 17 defines p-values for each of the parameters measured in this study. The p-value indicates the percent confidence that the range of water quality concentrations obtained from samples collected at the Mosby Bridge (Site 4) historic water quality are significantly different from the range of concentrations obtained from 1999-2000 through water quality monitoring of Sites 1-9 for this study.

Table 17. Table of p-values ($p < 0.05$) for total suspended solids, fecal coliform, total phosphorous, nitrates/nitrites, and total dissolved solids; comparison of historic water quality data from the Mosby Bridge (Site 4) to cumulative water quality data for Sites 1-9 within the study area ($p < 0.05$ with 8 degrees of freedom)

Parameter	June 5, 2000	July 20, 2000	August 19, 1999	August 27, 2000	September 27, 1999	November 11, 2000
Total Suspended Solids	0.7990	0.309	0.7901	0.7350	0.7323	0.4321
Fecal Coliform	0.2201	n/a	0.9981	0.6325	0.6702	
Total Phosphorous	0.8764	n/a	0.0016	0.3885	n/a	0.3863
Nitrates/Nitrites		n/a	0.8703		0.6244	0.5039
Total Dissolved Solids	0.0017	0.010	0.0150	0.0016	0.0020	0.0023

If the p-value is low, less than 0.05, then we accept the hypothesis that we can not determine with confidence that there is a difference in the concentrations of water quality samples from Sites 1-9 compared to the Mosby Bridge (Site4) water quality data. The concentration of total dissolved solids at Sites 1-9 are not significantly different from the concentrations measured at the Mosby Bridge (Site 4). The concentrations of total phosphorous were also not significantly different on August 19, 1999.

If the p-value is high, greater than 0.05, then there is a probability that the concentrations of each water quality parameter measured at Sites 1-9 are significantly different from the water quality concentrations measures at the Mosby Bridge (Site4). Total suspended solids, total phosphorous, nitrates/nitrites, and fecal coliform concentrations for Sites 1-9 were likely to be different from samples taken at the Mosby Bridge (Site 4) on any given sample day.

Figure 28 shows the magnitude of change in concentrations of fecal coliform for two sample periods, August 19, 1999 and August 27, 2000, between sample sites when

compared to data taken at the same time and using the same methods at the Mosby Bridge (Site 4). The zero line in the graph represents Site 4 data. All other site data are subtracted from the Mosby data in order to calculate the difference between sites in relation to Site 4. For example, on August 19, 1999 Site 4 had a fecal coliform concentration of 2730 count/100 ml and Site 1, on the same date, was measured at 630 count/100 ml. The resulting calculation entered in Figure 28 is $(2730 - 630 = 2100$ count/100 ml). This process was carried out for each sample site represented in Figure 28.

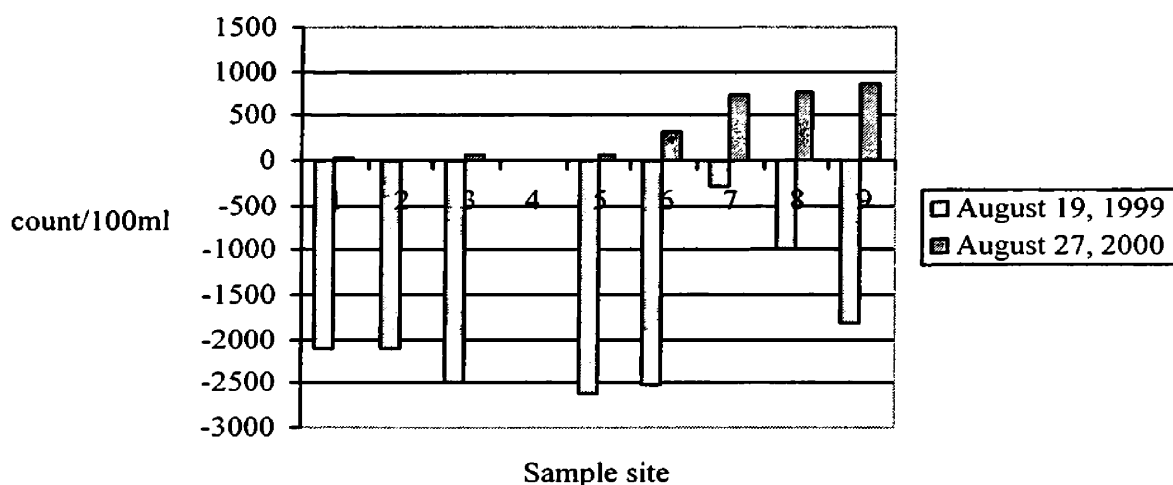


Figure 28. Variation of fecal coliform concentrations in respect to Site 4 for Sites 1-9 within the study area

This variation in concentrations of each parameter per sample site in relation to Site 4 could be caused by many factors. Local site conditions and activities may affect concentrations of different parameters. Figure 29 shows the comparison of pictures of Site 4, Site 7, and Site 1 within the study area. The differences in vegetative and hydrologic characteristics are shown in Table 18.

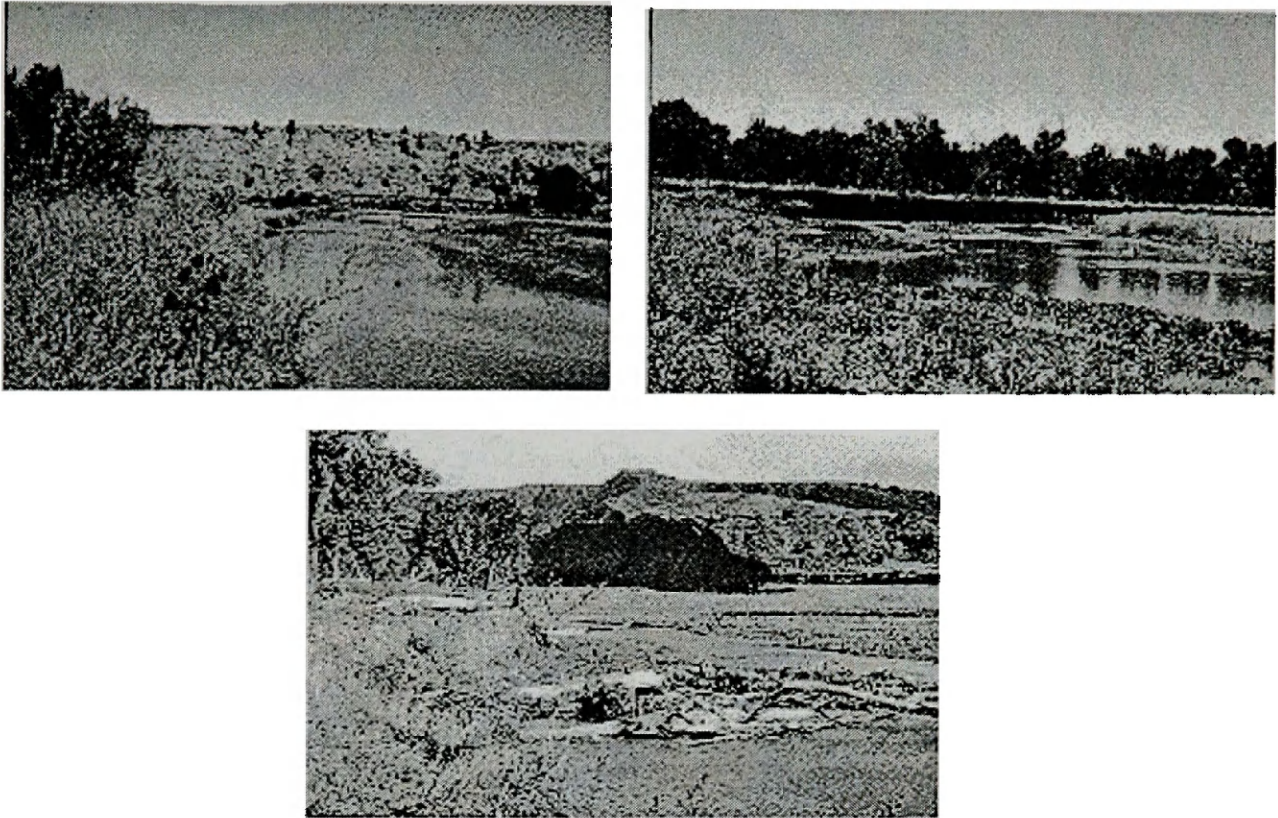


Figure 29. Summer season pictures taken looking downstream, clockwise from top left Site 4, Site 7, and Site 1; river flow is approximately 45 cubic feet per second (cfs)

Table 18. Vegetative and hydrologic site descriptions of Sites 4, 7, and 1 represented in Figure 29. Adapted from the RWRP Health Evaluation for Large Rivers 1999.

Site Number	Habitat Type/ Community Type	Lotic Inventory Derived Health Score	Channel Bottom Composition	Percent Human and Natural-Caused Bare Ground
4	Common Spikesedge Habitat Type (dominant species- yellow sweet clover)	81% (healthy but with problems)	50% cobble and 50% silt/clay	<5%
7	Great Plains cottonwood/ recent alluvial bar Community Type	76% (functioning with problems)	75% cobble 25% silt/clay	<5%
1	Unclassified upland (dominant species- mature Great Plains cottonwood and western wheatgrass)	62% (non-functioning)	25% cobble 25% gravel 50% sand/silt	25%

For the purposes of evaluating the entire Musselshell River from its headwaters in the Big Belt Mountains to its confluence with the Missouri River the Mosby Bridge water quality

station (Site 4) works well for evaluating the spatial and temporal trend in concentrations of total dissolved solids from Roundup, Montana to Mosby, Montana (Fig. 30).

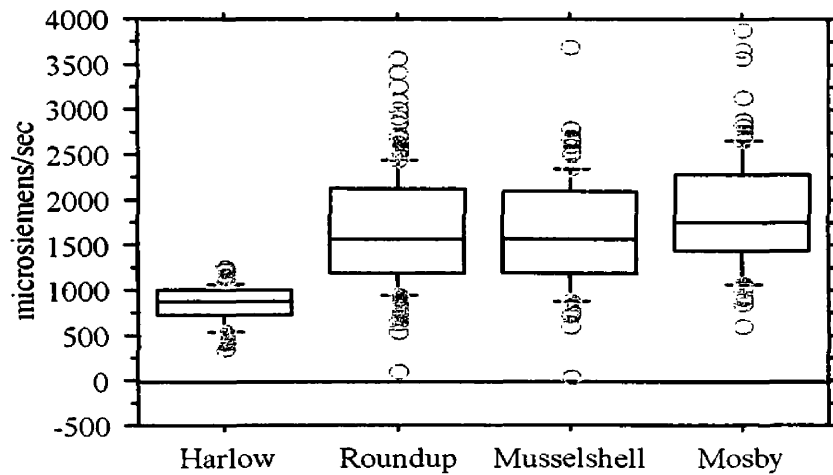


Figure 30. U. S. Geological Survey conductance data for the Musselshell River from Harlow, Montana to Mosby, Montana (1979-1999)

Further analysis of other water quality parameters for the same USGS gauging stations represented in Figure 30 may show similar trends. This data is available but was not analyzed within the scope of this thesis.

RECOMMENDATIONS

Continued public outreach, participation, and cooperation with local operators, landowners and communities is critical to the success of any watershed monitoring and/or restoration plan (George 1996). It is my belief that more improvements to water quality and riparian health will be realized along the Lower Musselshell River if local participants and communities can be shown the importance and means to creating a clean and healthful environment. This realization is fundamental to the processes of the U.S. Clean Water Act and the goals of the Montana Department of Environmental Quality Total Maximum Daily Load plans (TMDLs) for the State of Montana. Workshops, tours, field trips, and community involvement are a necessary means to these ends.

Workshops for landowners were well attended. They focused on technical aspects of irrigation, water quality monitoring, riparian health assessments and identification and control of invasive weeds. These workshops were successful and were an excellent way to disseminate a lot of pertinent information to the people involved and cooperating in the study. Local schools participated in hands-on field trips to local creeks. A total of 103 students and teachers participated in the field trips. Day long curricula for elementary and High school students were prepared. The field trips focused on local water quality issues and monitoring techniques, and riparian health assessments and plant identification. Future monitoring should incorporate education and workshops into each aspect of the project.

Further monitoring and evaluation of water quality and riparian corridor condition and function should continue. The purpose of the monitoring and evaluation has two key components. Monitoring and evaluation of water quality and riparian corridor condition and function will continue to foster a general understanding of the ecology of a Northern Great Plains river and the effects of land management and flow attenuation on its ecology and water quality.

Further monitoring and evaluation of water quality will help thwart the problems being faced on the Tongue River, Montana due to the discharge of saline ground waters by coal-bed methane development in the Tongue River watershed. Lack of current and sufficient water quality data along the Tongue River is making it difficult for irrigators and landowners to prove there is a detrimental effect from this discharge to surface waters. Current and sufficient data along the Lower Musselshell River could be used to substantiate the possible effects of development of natural resources within the Lower Musselshell River water shed.

A web page has been developed for the Lower Musselshell River Study and is being housed at, www.rwrp.umt.edu. This web page will provide links to vegetation and water quality data and provide an overview of the Riparian and Wetland research program study of the Lower Musselshell River. The Lower Musselshell River Study final report for the Montana Department of Environmental Quality and this thesis are available within the Lower Musselshell River Study web page housed at www.rwrp.umt.edu.

FURTHER DISCUSSION

The Musselshell River is a dynamic river system. The hydrology, soils, vegetative characteristics, and land management in the area compound the difficult task of analyzing water quality data and evaluating the factors which affect water quality (Tiedemann and Higgins 1989). Three fundamental processes/characteristics of the Lower Musselshell River which have a large effect on the ecology of the river and landowner operations are irrigation and water management, riverbank stability and sediment transport, and the concentration of total dissolved solids in the water column. The following discussion focuses on these three processes/characteristics.

Irrigation and water management plays a pivotal role in the water quality and quantity of the Musselshell River (Musselshell River Basin Water Management Study 1998). Irrigation withdrawals reduce the dilution power of the river and increase concentrations of many natural and unnatural constituents above acceptable levels via remobilization and evaporation (Musselshell River Basin Water Management Study 1998). Withdrawals also affect bank stability and subsequent bank erosion potential (Ponce and Lindquist 1990).

Irrigation withdrawals and drainage affect baseflow augmentation which affects water tables and produces dewatering effects (Eheart and Tornil 1999). Base flow augmentation is the temporary storage of subsurface water in floodplains, stream banks, and/or stream bottoms during the wet season for later release in the dry season (Ponce and Lindquist 1990). Dewatering and water table declines occur in the Musselshell River due to irrigation withdrawals which are taken directly from the river. Reduction in baseflow augmentation decreases river bank stability and negatively effects water quality (Ponce and Lindquist 1990, and Eheart and Tornil 1999). Decreases in bank stability will increase the potential for erosion and increase bed sediment loads and total suspended sediment loads in the water column (Ponce and Lindquist 1990). Water table declines due to irrigation withdrawals and water management also reduce the hydrologic and geomorphic processes necessary for the establishment of woody riparian vegetation such

as Great Plains cottonwood (*Populus deltoides*) and sand bar willow (*Salix exigua*) (Rood and Mahoney 1995).

The Musselshell river is situated in a myriad of marine, lacustrine, and alluvial sediments, which are primarily fine grained sand, silts, and clays. Clays and loams dominate the uplands and sandy loams dominate the floodplain (Lindahl 1993). The physical and chemical properties of fine grained sediments are of growing interest in terms of the role of erosion in controlling the properties of sediments at the source and the transport of particulate through river systems (Moore 2000 and Walling 1988). Increased awareness of sediment transport in movement of contaminants through land and aquatic environments is important for the purposes of understanding variations in concentrations and loading over time within a river system. Channel storage of suspended sediments and solids is also significant in downstream sediment yields (Walling 1988). Storage and remobilization of sediments is a dominant mechanism in the concentrations and loading of sediments and other water quality constituents (Moore 2000 and Walling 1988). It is important to understand the mechanisms of sediment storage and remobilization in a river channel. Remobilization of stored sediments may skew the results of land management improvements through prolonged release from bed storage even after a disturbance (Walling 1988).

Physical and chemical properties of sediments influence bioavailability, long term fate, and potential for interaction between particulate and soluble phases of many chemicals (Walling 1988). Sediments and the surrounding substrate are an important sink for nutrients and an important mechanism for the redistribution in time and space of these nutrients.

Total Dissolved Solids

The Lower Musselshell River is actively cutting through many layers of geologic history. The Bear Paw shale Formation and Hell Creek Sandstone Formation are the dominant rock types found in the study area. They are highly erodible and help to form the topography of the surrounding area. Both of these formations represent the deposits at the

margins of an ancient cretaceous sea, which inundated the region for millions of years as it made its final retreat eastward. This ancient sea deposited salts that are now seen as white bathtub rings around reservoirs or along the perimeter of dried river beds.

Sandstone and shale of the Hell Creek Formation, which are the youngest consolidated rocks in the area, overlie the shale of the Bear Paw Formation. The present river bed of the Lower Musselshell River has cut down to the upper portion of the Bear Paw Shale Formation.

The occurrence of salts in the deep rocks of the region is natural. The processes which leach these salts out are natural and man-made (Miller 1980). In irrigated uplands above the river bottoms irrigation water leaches salts out of the soil at a faster rate than would typically occur. Leached salts accumulate in depressions forming saline seeps which are unproductive for crop growth, or leached salts flow into the river.

Of the water quality parameters measured, including salinity, nitrogen and phosphorous levels, fecal coliform (bacteria), and sediments; salinity is the most important water quality parameter specific to operations of hay and small grain production in irrigated fields (Musselshell River Basin Water Management Study 1998 and Miller 1980).

Total dissolved solids is a measure of mineral constituents dissolved from rock and soils. It includes all material that is in solution in the water column. Concentrations of total dissolved solids are consistent throughout the study area and concentrations increase with reduced flows. High values for total dissolved solids are normal (naturally occurring levels not determined), due to natural and man-made saline seeps and underlying cretaceous shale formations such as the Bear Paw Shale (Miller 1980 and Bahls 1980).

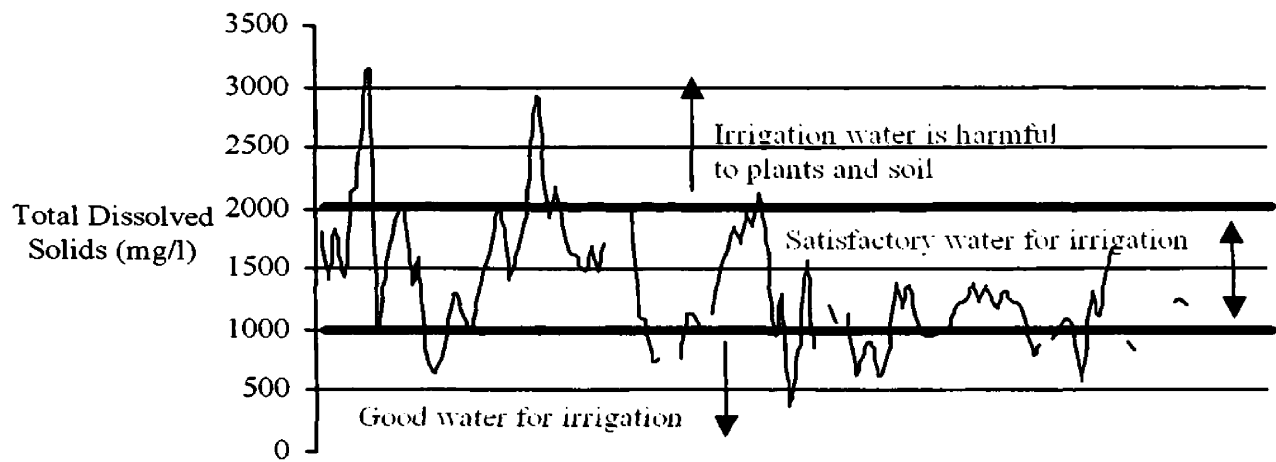


Figure 31. Concentration of total dissolved solids for the river at the Mosby Bridge; 1979-2000

Figure 31 shows that from 1979-2000 the concentrations of total dissolved solids were satisfactory for irrigating (U. S. Department of the Interior 1998). The periods of the year when there is the greatest chance that irrigation water pulled from the Musselshell River will be marginal or harmful to plants and soil are during August and September or during drought years where water used for irrigation is pulled from pools in the river channel. Pooled water evaporates leaving behind salts which continue to concentrate in the pools.

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GLOSSARY

Aggradation — the raising of the bed of a watercourse by the deposition of sediment.

Algae — any organisms of a group of chiefly aquatic microscopic nonvascular plants; most algae have chlorophyll as the primary pigment for carbon fixation. As primary producers, algae serve as the base of the aquatic food web, providing food for zooplankton and fish resources. An overabundance of algae in natural waters is known as eutrophication.

Algal bloom — rapidly occurring growth and accumulation of algae within a body of water. It usually results from excessive nutrient loading and/or a sluggish circulation regime with a long residence time. Persistent and frequent blooms can result in low-oxygen conditions.

Alluvial soil — sediments (e.g. clay, silt, sand, gravel, rubble, and boulders) deposited by running water, ordinarily occurring on floodplains and at the base of ridges and slopes.

Alluvial terrace — deposits of alluvial soil that mark former floodplains. Typically, a floodplain may have several sets of alluvial terraces at different elevations and of different ages (the higher the elevation, the older the age).

Alluvium — sediments deposited on land by streams and rivers.

Anticline — a fold in bed rock or shale formation that forms a prominent ridge with land sloping downward on both sides from the common crest or ridge.

Aquatic ecosystem — complex of biotic and abiotic components of natural waters. The aquatic ecosystem in an ecological unit that includes physical characteristics (such as flow or velocity and depth), the biological community of the water column and

benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and nonliving components of the aquatic ecosystem interact and influence the properties and status of each component.

Background levels — levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.

Bars (alluvial) — are sediment depositional features. Examples include: 1) point bars - bars that are formed on the inside of a meander channel, 2) side bars - bars that are formed along the edges of relatively straight sections of a river, 3) mid-channel bars - these are found within the channel and generally become more noticeable during low flow periods, and 4) delta bars - formed immediately downstream of the confluences of a tributary and the main river.

Baseflow—is the period in the water year when surface flow of a river is dominated by inputs from groundwater.

Bedload sediment — portion of sediment load transported downstream by sliding, rolling, and bouncing along the channel bottom.

Beneficial uses — those uses specified in water quality standards for each waterbody or segment whether or not they are being attained, for example, swimming, bathing drinking water, and agriculture.

Benthic — refers to material at the bottom of an aquatic ecosystem. It can be used to describe the organisms that live on, or in, the bottom of a waterbody.

Bioassessment — the evaluation of an ecosystem using integrated assessments of habitat and biological communities in comparison to empirically defined reference conditions.

Browse — shrubby and woody forage consumed by wildlife. It is defined as the leaves and current year leader growth of shrubs and broadleaf trees less than six feet in height.

Community (plant community) — an assembly of plants living together, reflecting no particular ecological status.

Community type — an aggregation of all plant communities distinguished by floristic and structural similarities in both overstory and undergrowth layers. A unit of vegetation within a classification. For the purposes of this document, a community type represents seral vegetation, and is never considered to be climax.

Concentration — amount of a substance or material in a given unit volume of solution.

Cretaceous — a period of geologic time characterized by flowering plants and the disappearance of dinosaurs. A term used to designate the geologic era that a rock formation or sedimentary deposit belongs.

Diatom—microscopic single celled organism or multi-celled algae found floating or attached in freshwater ecosystems; typically a good indicator of nutrient loading to the water column.

Diversity — the kind and amount of species in a community per unit of area.

Drainage basin — a part of a land area enclosed by a topographical divide from which direct surface runoff from precipitation normally drains by gravity into receiving water. Also referred to as a watershed, river basin, or hydrologic unit.

Ecosystem—a community of plants, animals, and other living organisms together in a unique physical environment considered as a unit, for example, riparian ecosystem or a forest ecosystem.

Ephemeral stream — a stream or stretch of a stream that flows only in direct response to precipitation. It receives no water from springs and no long-continued supply from melting snow or other surface source. Its stream channel is at all times above the water table. These streams do not flow continuously during periods of as much as one month.

Floodplain — an alluvial plain caused by the overbank deposition of alluvial material. They typically appear as flat expanses of land bordering a stream or river. Most floodplains are accompanied by a series of alluvial terraces of varying levels.

Fluvial — pertaining to or produced by the action of a stream or river.

Gated pipe—Poly-vinyl-carbon (PVC) pipe typically measuring 8-12cm in diameter placed on level or gently sloping ground to convey water from a pump station or stream diversion. Small openings evenly spaced along the pipe are manually opened to release consistent water flow to a land-smoothed irrigated field.

Geomorphology — the study of the evolution and configuration of landforms.

Graminoid — grass or grass-like plant, such as species of the Poaceae (grasses), Cyperaceae (sedges), and Juncaceae (rushes).

Groundwater — that portion of the water below the surface of the ground whose pressure is greater than atmospheric pressure.

Habitat type — the land area that supports, or has the potential of supporting, the same primary climax vegetation. A habitat type classification is a vegetation based

ecological site classification. It is based on the potential of the site to produce a specific plant community (plant association). It has been used to classify grasslands, shrublands, woodlands, and forests throughout western United States. This system is currently being applied to lands in central and eastern United States.

Herbaceous — non-woody vegetation, such as graminoids and forbs.

Hydrology — the science dealing with the properties, distribution, and circulation of water.

Hydrophytic vegetation — any plant that grows in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water; represents plants typically found in wetlands and other aquatic habitats.

Infestation — as with weeds, a condition of land being occupied by a population of an unwelcome species.

Intermittent stream — a stream or stretch of stream which flows only at certain times of the year when it receives water from springs or from some surface source such as melting snow in mountainous or other cold tributary areas. They are usually divided with respect to the source of their water into spring-fed or surface-fed intermittent streams. These streams generally flow continuously during periods of at least one month or more during the year.

Invasive plant—commonly known as weeds; describes the tendency of a plant to spread or to invade healthy plant communities.

Lacustrine — pertaining to the sediments deposited at the bottom of lakes over time forming deposits of deep silts. Deposits may be exposed over geologic time.

Load/Loading — the total amount of material (pollutants) entering a system from one or more sources. Typically measured as a rate in weight per unit time.

Nitrate/nitrite—(NO_3^- / NO_2^-) chemical forms of elemental nitrogen which are readily available for use by plants; predominant form of nitrogen found in chemical fertilizers.

Nonpoint source — pollution that originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Nutrient—something that promotes growth or development; phosphorous and nitrogen are considered nutrients for plants and algae.

Overflow channel—an abandoned channel in a floodplain that may carry water during periods of high stream or river flows.

Perennial stream—a stream or stretch of a stream that flows continuously. They are generally fed in part by springs and their upper surface generally stand lower than the water table in localities through which they flow.

Periphyton—non-mobile (sessile) organisms that live attached to surfaces of rocks, woody debris, and mud in freshwater ecosystems.

Point source—pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Polygon — is the basic unit of inventory data collection used for the project. Due to the scale of photography and the linear nature of riparian-wetland systems, most polygons were drawn as single lines on the maps and photo overlays. However, when the area was large enough, the polygons were drawn as enclosed multi-sided areas.

Riparian area — a geographically delineated area having distinctive resource values and characteristics, containing both riparian and aquatic ecosystems. Riparian areas are associated with lakes, reservoirs, potholes, springs, bogs, wet meadows, and ephemeral, intermittent, or perennial streams. Riparian areas include wetlands.

Riparian fencing— installation of fence between uplands and the riparian area; a Best Management Practice (BMP) designed to reduce grazing pressures on associated river vegetation by reducing the duration and intensity of grazing in riparian areas.

Riparian or wetland ecosystem — the ecosystem located between aquatic and terrestrial environments. Identified by soil characteristics and distinctive vegetation that requires or tolerates free or unbound water.

Riparian or wetland species — plant species occurring within the riparian or wetland zone. Obligate riparian or wetland species require the environmental conditions associated with the riparian or wetland zone. Facultative riparian or wetland species are tolerant of these environmental conditions, but also occur in uplands.

Riverbank — that portion of the channel bank cross-section that controls the lateral movement of water.

Scour — to abrade and wear away. Used to describe the weathering away of a terrace or diversion channel or streambed. The clearing and digging action of flowing water, especially the downward erosion by stream water in sweeping away mud and silt on the outside of a meander or during flood events.

Sedge—grass-like plant that is typically found along the banks of rivers and streams and in wet areas; characteristically deep root system which helps reduce bank erosion. Sedge species can be generally identified by their structurally prominent edges.

Shrub — a multi-stemmed woody plant generally shorter than 4.8 m (16 ft).

Shrub browse—the consumption of shrub material, typically new growth, by wildlife and livestock.

Sinuosity — the degree to which a river or stream bends.

Stand — a plant community that is relatively uniform in composition, structure, and habitat conditions; a sample unit.

Stock water tank—typically an aluminum cylinder half buried in the ground and fed by groundwater wells for watering livestock away from rivers, streams, and ephemeral coulees.

Stream — a physical water feature defined as first to third order.

Streambank — that portion of the channel bank cross-section that controls the lateral movement of water.

Stream reach or reach — refers to a section of stream with certain attributes that separate sections from adjacent stream sections. The defining attributes are variable.

Substrate — bottom sediment material in a natural water system.

Suspended solids/sediment — Organic and inorganic particles suspended in and carried by water. Suspended sediment usually consists of particles smaller than 0.1 mm, although size may vary according to hydrological conditions.

Thalweg—the longitudinal segment of a river or stream which is characterized by having the highest velocity of flow and the deepest channel profile. The thalweg of a river meander is located nearer the cut-bank than the point bar.

Total Maximum Daily Load (TMDL)—Total Maximum Daily Load of a water quality toxin or water quality constituent , such as total dissolved solids, temperature, or fecal coliform which a water body can assimilate or carry without degrading the water quality of that water body. $TMDL = \text{Background} + \text{Non-point source load} + \text{Point source load} + \text{Margin of Safety or error component}$.

303 (d) list—part of the Federal Clean Water Act Section 303 (d); states are required to make a prioritized list of waterbodies, including rivers and streams that did not meet the water quality standards set by the Environmental Protection Agency or the State Department of Environmental Quality.

305 (b) report— statewide water quality assessment report which is required by Section 305 (b) of the Clean Water Act.

Total dissolved solids—measure of mineral constituents dissolved from rock and soils found dissolved in the water column. It includes all material that is in solution in the water column.

Transect — in this document a transect refers to a line drawn perpendicular to a stream. Along this transect, stream reach, geomorphological, and substrate information was collected.

Uplands — any area that does not qualify as a wetland because the associated hydrologic regime is not sufficiently wet to elicit development of vegetation, soils, and/or hydrologic characteristics associated with wetlands. Such areas occurring in floodplains are more appropriately termed nonwetlands.

Water quality criteria — levels of water quality expected to render a body of water suitable for its designated uses, comprised of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial uses.

Water table — the zone of saturation at the highest average depth during the wettest season; it is at least 15 cm (6 in) thick and persisting for more than a few weeks.